JOURNAL OF AGRICULTURAL RESEARCH

VOL. VIII WASHINGTON, D. C., FEBRUARY 26, 1917 NO. 9

A SQUASH DISEASE CAUSED BY CHOANEPHORA CUCURBITARUM[1]

By FREDERICK A. WOLF,

Botanist and Plant Pathologist, North Carolina Agricultural Experiment Station

INTRODUCTION

It was noted during the past season (1916) that summer squashes in the vicinity of West Raleigh, North Carolina, were attacked by a phycomycetous fungus, *Choanephora cucurbitarum* (B. and Rav.) Thaxter. Attention was directed to this fungus primarily because of the luxuriance of its fructifications on affected parts of squashes (*Cucurbita* spp.) and of the rapidity with which it destroyed such parts. A study was therefore made of the development of the disease and of the morphology of the causal organism. Conidial, sporangial, chlamydosporic, and zygosporic stages have been developed, and there have been made certain observations which are at variance with previously recorded facts relative to *C. cucurbitarum* and other species of the same genus. It is the present purpose, therefore, to record the results of this study as additional knowledge of this exceptionally interesting form and to indicate its importance as a parasite on the squash plant.

HISTORY AND DISTRIBUTION OF THE FUNGUS

This fungus has long been known to occur within the United States, having first been described in 1875 by Berkeley[2] as *Rhopalomyces cucurbitarum* from decaying squashes collected in South Carolina by Ravenel. The organism has subsequently been found in other States, as noted by Thaxter[3] in his account of the genus Choanephora. Dr. Thaxter himself collected the fungus on squashes at Waverley, Massachusetts, and on cultivated species of Hibiscus and a wild malvaceous plant at Eustis, Florida. He records the fact that the same plant is in the Curtis Herbarium at Harvard University under the name "*Aspergillus cucurbiteus*, Hillsborough, N. C., on squashes." He further examined specimens of the same fungus on squashes sent from New York by Prof. Peck and from Ohio by Prof. Morgan.

[1] Published with the permission of the Director of the North Carolina Agricultural Experiment Station.

[2] Berkeley, M. J. Notices of North American fungi. *In* Grevillea, v. 3, no. 27, p. 109. 1875.

[3] Thaxter, Roland. A New England Choanephora. *In* Rhodora, v. 5, no. 52, p. 97-102, pl. 46. 1903.

Clinton,[1] in 1903, reported the occurrence of the disease in Connecticut, and included photographic illustrations of the fungus on squash flowers. This species has also been noted in Brazil on the petals of a species of Hibiscus and on certain other plants, whence it was described by Möller[2] as *Choanephora americana*.

Numerous collections have been made during the past summer in the vicinity of West Raleigh, N. C., and in two other localities within the State,—Winston-Salem and Walnut Cove. Since these points are rather widely separated, it is believed that *Choanephora cucurbitarum* is generally present throughout the State. From reports received, unaccompanied, however, by specimens, there seems to be no doubt that the disease was present during the past season in other Southern States.

HOSTS OF THE FUNGUS

During the past summer the disease was found on several varieties of *Cucurbita pepo*, being most destructive on the "pattypan" types of summer squashes, commonly known as cymlings. The fungus has also been found on the fading flowers of cucumber (*Cucumis sativus*) althea (*Hibiscus syriacus*), scarlet hibiscus (*Hibiscus coccineus*), okra (*Hibiscus esculentus*), and cotton (*Gossypium herbaceum*). It appears to be parasitic, however, only upon the squash. Previous investigations, as has been indicated, reported the occurrence of *C. cucurbitarum* on squashes, *Hibiscus* spp., a wild mallow, and certain other plants.

ECONOMIC IMPORTANCE

The disease is probably not the cause of appreciable damage to squashes annually, but appears in epidemic form only under certain meteorological conditions. Conditions of high humidity and excessive rainfall were generally prevalent in the Southern States during the past summer, and are believed to be correlated with epidemics of the squash disease. At no time during the four preceding summers has the disease been sufficiently destructive to attract the writer's attention.

Since squashes are not a crop of any considerable financial importance to the market gardener in North Carolina, it is especially difficult to obtain figures on the loss due to this disease. The crop is very generally grown in home gardens, and even though a considerable proportion of the fruits decay, an ample crop for home use remains. All of the flowers have been observed to be blighted and all of the fruits destroyed on certain vines. Thaxter,[3] in discussing the injury by *C. cucurbitarum*, says: "It is undoubtedly often responsible for the destruction of no inconsiderable percentage of the crop." Clinton[4] states that "it no doubt often blasts the blossoms and may rot the fruit, also."

[1] Clinton, G. P. Report of the botanist. Diseases of plants cultivated in Connecticut. *In* Conn. Agr. Exp. Sta. 27th Ann. Rept., [1902]/3, p. 359, pl. 26. 1904.

[2] Möller, Alfred. Phycomyceten und Ascomyceten. p. 18, pl. 1, fig. 1–4. Jena, 1901. (Schimper, A. F. W. Botanische Mittheilungen aus den Tropen. Heft 9.)

[3] Thaxter, Roland. Op. cit.

[4] Clinton, G. P. Loc. cit.

APPEARANCE OF THE DISEASE

The symptoms of the disease on flowers and fruits of squashes is quite characteristic. The fungus covers the affected parts with a luxuriant crop of conidiophores, with no evidence of any vegetative mycelium. The fructifications of two other fungi, *Rhizopus nigricans* Ehr. and *Botrytis vulgaris* Fr., may appear on the surface of decaying squash fruits, but neither of them possesses the metallic luster which characterizes the fructifying filaments of *C. cucurbitarum*.

The first evidence of attack on the flowers usually appears on the day following the opening of these flowers. Early in the morning of the second day, the fungus will have reached its most luxuriant development, especially immediately after a shower, and the fading flowers will be covered by a dense coating of immature, white conidial heads. Within a few hours these fructifications will have matured and will have changed in color from white to brown and at length to purplish black. When staminate flowers are attacked, the mycelium may pass downward into the flower pedicel, converting the tissues into a soft, translucent condition. Abscission of the flowers generally occurs before the pedicels become invaded. The appearance of the disease on flowers and flower pedicels is shown in Plate 87, *A*.

When pistillate flowers are attacked, the fungus passes from the fading flower into the young squash. Incipient decay from infection through the corolla is shown in Plate 87, *D*, as is also complete decay involving the fruit in a soft, wet rot with a profuse envelopment of conidial branches. The decay of fruits progresses with remarkable rapidity, as is shown in Plate 87, *B*, *C*. The photographic exposure for figure *B* was made about 15 hours after the one for figure *C*, the squash, meanwhile, having been kept in a moist chamber. Occasional fruits were found in which the fungus appeared not to have gained entrance through the corolla.

ETIOLOGY AND DEVELOPMENT OF THE FUNGUS

Choanephora cucurbitarum, the cause of this squash disease, is unique in that it is the only known American representative of the family Choanephoraceae. Two other species have been described from India, one *C. infundibulifera* (Curr.) Cunn. on the flowers of *Hibiscus rosa-sinensis* and the other, *C. Simsonii* Cunn. on *Ipomoea rubro-coerulea* and *Zinnia elegans*. The former of these was described by Currey [1] in 1873 as Cunninghamia, a new genus of mucedinous fungi, and was referred by Cunningham [2] in 1879 to the Mucorineae.

[1] Currey, Frederick. On a genus in the order of Mucedines. *In* Jour. Linn. Soc. [London], Bot., v. 13, p. 333–334, pl. 7. 1873.

[2] Cunningham, D. D. On the occurrence of conidial fructification in the Mucorini, illustrated by Choanephora. *In* Trans. Linn. Soc. London, s. 2, Bot., v. 1, p. 409–422, pl. 47. 1879.

CONIDIAL STAGE

Observations on the development of the conidial stage agree essentially with those of Thaxter.[1] The erect conidiophores, whose comparative size is shown in Plate 87, *A*, are whitish at first, but at maturity change to a distinct metallic luster. They are broadest at the upper extremity, which becomes dilated into a capitate vesicle. From this capitulum, a few to a dozen or more ramuli arise, which in turn become vesicular (Pl. 85, *A*). The ramuli commonly remain simple, but occasionally branched ones are present. By a process of budding, an early stage of which is represented in Plate 85, *B*, the capitella become covered with a densely compacted layer of conidia (Pl. 85, *D*). The conidia vary in outline from oval to elliptical and are conspicuously marked by longitudinal striations (Pl. 85, *C*), some of which anastomose. They vary in size from 15 to 25 by 7.5 to 11 μ and in color from light brown to reddish brown. The base of each conidium is provided with a hyalin appendage, the adherent portion of the sterigma. When the ramuli are broken off, scars as shown in Plate 85, *E*, are evident on the primary vesicle.

Variations from this normal course of development have been noted. Conidia may arise directly from the surface of the primary head, a condition noted both by Thaxter [1] and myself and which is characteristic of the genus Rhopalomyces. Occasionally the conidiophore branches and gives rise to two primary heads on each of which a layer of conidia is formed. These are not necessarily depauperate forms, since they appear in cultures with normal well-developed conidial fructifications.

GERMINATION OF CONIDIA

Germination readily follows when the conidia are sown either on nutrient agar, such as bean, potato, glycerin, or cellulose agar, or in drops of water. Cunningham [2] states that germination of conidia of *C. infundibulifera* does not occur in water. Germination of *C. cucurbitarum* does not proceed, however, with equal rapidity in water and in nutrient agar, as shown by Plate 85, *G*, *H*, the former of which represents growth on nutrient agar 3½ hours after the commencement of cultivation, and the latter growth in water, after an equal period. Conidia were obtained from the same source in both cases and were germinated under the same conditions of light and temperature.

The first evidence of germination is the considerable increase in size which takes place before the emergence of the germ tube. Typically a single lateral germ tube is formed, occasionally two, which in some cases arise from the extremity. As a rule, the germ tubes will have emerged within two hours after sowing. The rate of subsequent development is indicated in the stages represented in Plate 85, *I*. Plate 85, *I*, *a*, shows

[1] Thaxter, Roland. Op. cit. [2] Cunningham, D. D. Op. cit.

an early stage in the development of a hypha from each of two conidia which were kept under constant observation and outlined at 15-minute intervals, with the aid of a camera lucida. Each successive stage is thus 15 minutes older than the preceding one, making an interval of an hour between Plate 85, *I*, *a*, and Plate 85, *I*, *e*. Under favorable conditions of temperature (room temperature during July and August) the mycelium will have profusely covered a 10-cm. nutrient-agar plate within 24 hours and will have fruited luxuriantly. Thaxter[1] found that this fungus fruits abundantly in a moist chamber when cultivated on squash tissues, but that fructifications very rarely appear on potato agar and similar nutrients in tubes.

SPORANGIAL STAGE.

The sporangia of *C. americana*, which is regarded as synonymous with *C. cucurbitarum*, was described, as has been indicated, by Möller.[2] Thaxter states that he was never able to obtain sporangia of this organism, although he repeatedly cultivated it under unfavorable conditions of nutrition, which were held by Cunningham[3] to favor their production in *C. infundibulifera*. Such unfavorable conditions are present when the artificial medium is exhausted by the vegetative growth of the fungus and when the mycelia developed from conidia produced in artificial culture. When grown under artificial conditions, *C. infundibulifera* appeared to lose its vigor progressively, since no reproductive structures developed in cultures the third generation removed from the natural host. Neither were sporangia formed on the host in the natural state, a condition similar to that found by the writer with *C. cucurbitarum*. In fact, the conidial stage only has been found on squashes, the other stages having all appeared in culture.

Sporangia generally appear with conidial fruits, but have been formed alone on one set of cellulose-, bean-, and glycerin-agar plates which were continuously kept in the dark. Other series of cultures on the same kind of media when grown in darkness developed a few of both types of asexual spores. A different strain of fungus was used in these series. Certain cultures on cellulose agar, when kept in the light, developed only sporangia. Evidently light alone is not the determining factor in the formation of conidia and sporangia in *C. cucurbitarum*. Cunningham[3] never obtained sporangia apart from the conidial form.

Mature sporangia are present as early as mature conidia. They usually form most abundantly at the center of the colony on plate cultures. Sporangia are first evident as pendent, white, globular enlargements The sporangium becomes separated from the sporangiophore by a globular columella, which can best be seen when mature sporangia are burst (Pl. 85, *L*). At maturity the sporangia are black and vary in diameter from 35 to 160 μ. Diminutive sporangia have as few as two or three

[1] Thaxter, Roland. Op. cit. [2] Möller, Alfred. Loc. cit. [3] Cunningham, D. D. Op. cit.

spores. The spores are ovoidal or elongated rarely inequilateral and of the same color as the conidia. They are somewhat larger than the conidia, being 18 to 30 by 10 to 15 μ. They lack the striations which characterize the conidia, but are unique in that they are provided with two or three terminal or lateral hyalin appendages, from each of which a tuft of 12 to 20 hairlike processes extend (Pl. 85, *N*). These ciliate processes are from 1 to 1½ times as long as the spores.

GERMINATION OF SPORANGIOSPORES

The germination of these spores is quite similar to that of conidia Within two or three hours after the spores are placed in nutrient media there is an increase in size of the spores, followed by the emergence of one or two lateral germ tubes (Pl. 85, *J*). Within a few hours a profusely branched mycelium is formed, which in 24 to 48 hours has matured a crop of sporangia and conidia.

CHLAMYDOSPORES

The mycelim in 4- to 5-day-old cultures on nutrient agar is commonly septate. Not infrequently well differentiated chlamydospores, as shown in Plate 85, *O*, will have formed within this time. In cultures 2 weeks old chains of chlamydospores, as represented in Plate 85, *M*, are sometimes developed. No chlamydospore formation occurred in the form which Thaxter[1] had under observation. These bodies have never been observed to germinate.

ZYGOSPORIC STAGE

Cunningham observed zygospore formation in the two Indian species of Choanephora, and his account of the development of *C. infundibulifera*[2] contains a detailed description of this process. Zygospores of *C. cucurbitarum* appear not to have been observed prior to the present study. No noteworthy differences are presented by the American species when contrasted with the Indian forms. A club-shaped branch first arises from each of two adjacent mycelial filaments. These gradually enlarge and become densely filled with granular protoplasm. The contents tend to accumulate in the apical extremity, and a septum forms, separating the gamete from the suspensor. When two of these branches are situated sufficiently close together, their bowed tips come in contact and the gametes become flattened along the opposed surfaces. The partition is then absorbed and the two gametes fuse. Such a stage is represented in Plate 86, *B*, *C*, at which time the two saccular suspensors are quite clear and empty as contrasted with the immature zygospore, which is convex on the upper side and is filled with coarse granules and numerous yellowish oil globules. As the zygospore matures, this convexity

[1] Thaxter, Roland. Op. cit.

[2] Cunningham, D. D. Op. cit.

is increased until the terminal walls of the suspensors tend to be in the same plane (Pl. 86, *E*), and the suspensors appear to support it from one side. Meanwhile the exospore has thickened, become dark brown in color, and the oil globules have fused to make one large globule, which occupies one-third to one-fourth of the volume of the ripe zygospore. Zygospores vary in size from 50 to 90 μ in the longest diameter.

Mature zygospores were first observed in nutrient agar cultures 48 hours old which had been planted with conidia taken from squash flowers. They appeared, however, in only a small number of isolation cultures prepared in this way. They are formed embedded within the agar and on its surface and can be seen with the unaided eye as numerous black specks when the isolation plates are held against a white background. Conidia and sporangia are always present in these plates. All attempts to germinate these zygospores have thus far met with failure. Furthermore, all attempts to determine the conditions necessary for zygospore formation have been futile. Curiously, no zygospores appeared in subcultures from cultures in which zygospores were present; nor have they ever been noted in culture except when the conidia for making these cultures were taken directly from the host plant. It was presumed that this might be due to a loss of vigor in artificial culture. It will be recalled that cultures of *C. infundibulifera* three generations removed from the natural host failed to form asexual spores. No such failure to form conidia and sporangia appears to occur in *C. cucurbitarum*, since it has been grown for 15 generations with no resultant decrease in the luxuriance of its asexual fructifications. Numerous cultures have been obtained from single conidia and sporangiospores with the view of determining whether in this species zygospore formation was conditioned by heterothallicism. Thus far, however, no evidence of this separation of sexes has been found.

When material for studying zygospore development was at hand, the press of other duties prevented the making of a detailed study of the process. Subsequently, it has been impossible to develop zygospores. However, several blocks of agar containing zygospores were fixed, sectioned, and stained. Unfortunately, only a few of the stages were exhibited in these sections. Plate 86, *A*, represents an early stage in which the gametes have been separated from the suspensors. Gametes, suspensors, and vegetative mycelium (Pl. 86, *D*) are found to be multinucleate. It is hoped subsequently to be able to furnish an account of the conditions necessary for zygospore formation and of the cytological phenomena accompanying this process.

Since no complete account of all of the spore forms of this organism has ever been given, it seems desirable to present herewith a brief technical description, together with its synonomy and the known list of hosts.

Choanephora cucurbitarum (Berk. and Rav.) Thaxter

Choanephora cucurbitarum (Berk. and Rav.) Thax., 1903, *in* Rhodora, v. 5, p. 97–108, pl. 46.
Rhopalomyces cucurbitarum Berk and. Rav., 1875, *in* Grevillea, v. 3, no. 27, p. 109.
Rhopalomyces elegans, var. *Cucurbitarum* Marchal, 1893, *in* Rev. Mycol., ann. 15, no. 57, p. 11.
Aspergillus cucurbiteus Curtis, in Harvard Herbarium.
Choanephora americana Möller, 1901, Phycom. u. Ascom., p. 18, pl. 1, fig. 1–4.

Sporangia pendula, globosa, solitaria, polyspora, nigra, 35–160 μ diam.; stipite nitido-violaceo; columella globosa; sporis ovoideis vel ellipsoideis, levibus, brunneo-rufis 18–30×10–15 μ. utrimque interdum atque lateribus penicello ciliorum auctis; ciliis 25–45 μ longis. Condidiophoris usque 6 mm. longis, nitido-violaceis; apice vescicula unica vel pluribus capitatis muriculatis terminatis; conidiis in vescicula capitatim insertis ovoideis longitrorsum striatis, brunneo-rufis, appendicula basilare hyalina, 15–25×7.5–11 μ. Chlamydosporae globosae vel oblongo-ellipsoideae. Rami zygosporae arcuati, zygosporis inaequilateralibus, unico globulo olei genente, 50–90 μ diam.

Hab. in fructibusque floribus vivis Cucurbitae peponis ac in floribus languidis Hibisci esculenti, H. coccinei, H. syriaci, Gossypii herbacei, Cucumis sativii aliisque malvacearum, Americae Bor., atque in petalis adhuc stantibus Hibisci aliisque plantae partibus dejectis, Blumenau brasiliae.

PATHOLOGICAL ANATOMY

Diseased tissues from squash fruits and flower pedicels were fixed, sectioned, and stained for this portion of the study. Mycelium was found to be present in all of the tissues that were involved in softrot or wetrot, with no evidences of disintegration in advance of the mycelium. It is both intercellular and intracellular, as shown by Plate 85, *F*, *K*, figure *F* representing the invaded tissue of the flower pedicel and *K* that of squash fruit. Parasitism appears to be of the necrotic type, with little or no transformation of the cell wall substance. Growth of the fungus on cellulose agar gave no evidence of the secretion of cellulase. Evidence of the presence of cellulase and cytase was further sought, with negative results in 14-day-old cultures of *C. cucurbitarum* on sterilized squash fruits. The fluid from these cultures was filtered through a Chamberland filter and pieces of raw fruits were introduced under aseptic conditions into this sterile filtrate.

DISSEMINATION OF THE FUNGUS

A microscopic examination of the inner surface of the corolla tube and of the filaments of the stamens revealed the fact that conidia of *C. cucurbitarum* are commonly present in open squash flowers. Thirty of the 35 flowers which had opened on the morning of July 6, and which were examined in the afternoon of that day, contained conidia. On the afternoon of the 7th, conidia were present in all the flowers examined,—27. On the 8th, 7 flowers were picked before 7 a. m., and all had conidia within them. On the 10th, conidia were present in 25 flowers which had not yet closed. Since various species of bees so commonly visit squash flowers, a limited number were examined to determine whether they were instrumental in distributing the conidia. The bees, when captured among the

squash plants, were placed in test tubes washed in a small quantity of water, and the wash water was examined by placing drops of this water on a microscopic slide. Conidia were quite commonly present in this water. The striped and spotted cucumber beetles (*Diabrotica vittata* and *D. punctata*, respectively) were also found to be carriers. The wind is also an agent in the dissemination of this fungus, as determined by a series of 13 agar plates which were exposed in a field of squashes on the morning of July 11. On the following day *C. cucurbitarium* had developed on all of these plates.

SUMMARY

(1) *Choanephora cucurbitarum* is parasitic upon summer squashes, causing a blight of the flowers and a rot of the fruits.

(2) The disease has been the cause of very considerable losses during the past summer.

(3) Infection of fruits occurs, for the most part, by the passage of the fungus from the fading corolla to the young squash.

(4) Various species of bees, striped and spotted cucumber beetles, and currents of air are agents of dissemination of the conidia.

(5) The fungus has been found on languid flowers of cucumber, althea, okra, cotton, and other malvaceous plants.

(6) *C. cucurbitarum* is the only known American species of this genus.

(7) The conidial stage alone appears on affected parts of the several host plants.

(8) Sporangial, chlamydosporic and zygosporic stages have been developed in artificial culture. None of these stages have previously been reported by investigators within the United States.

(9) All of the reproductive stages have been noted in the same culture on nutrient agar. Conidia, sporangia, and zygospores may mature in cultures 24 to 48 hours old. No decrease in luxuriance of asexual fructification has been found in culture on nutrient agar.

PLATE 85

Choanephora cucurbitarum:

A.—Immature conidiophore with ramuli developing on the primary vesicle. ×100.

B.—Budlike processes the beginning of conidial formation on the capitellum. ×100.

C.—Conidia. ×250.

D.—Mature capitulum covered with a layer of conidia. ×125.

E.—Primary vesicle from which ramuli have been detached. ×100.

F.—Mycelium in tissue of squash flower pedicel. ×75.

G.—Germination of conidia 3½ hours old in nutrient agar. ×250.

H.—Germination of conidia 3½ hours old in water. ×250.

I.—*a*, Early stage in germination of conidia in hanging drop; *b*, growth of mycelium from same conidia as figure *a* drawn 15 minutes later; *c*, one-half hour later than figure *a*; *d*, 15 minutes later than figure *c*; *e*, one hour later than figure *a*. ×250.

J.—Germination of sporangiospores. ×250.

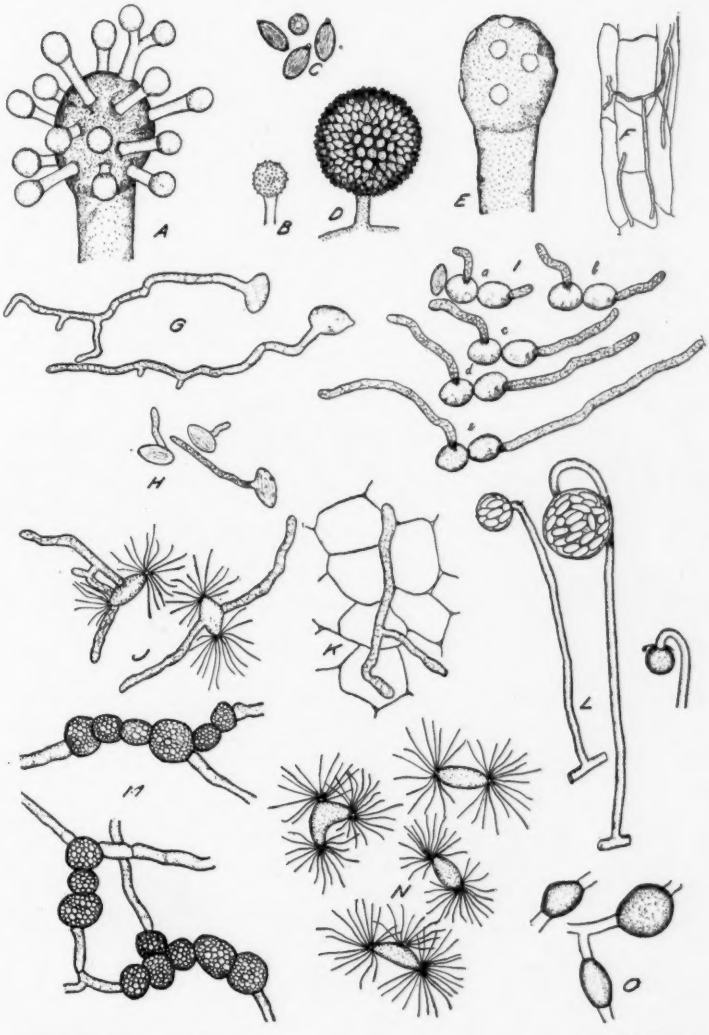
K.—Mycelium of the fungus within the tissues of squash fruit. ×250.

L.—Variation in size of sporangia and columella. ×70.

M.—Chlamydospores borne in chains in old cultures. ×250.

N.—Sporangiospores with tufts of hairlike appendages. ×250.

O.—Chlamydospores formed singly in 4-day-old cultures. ×250.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O

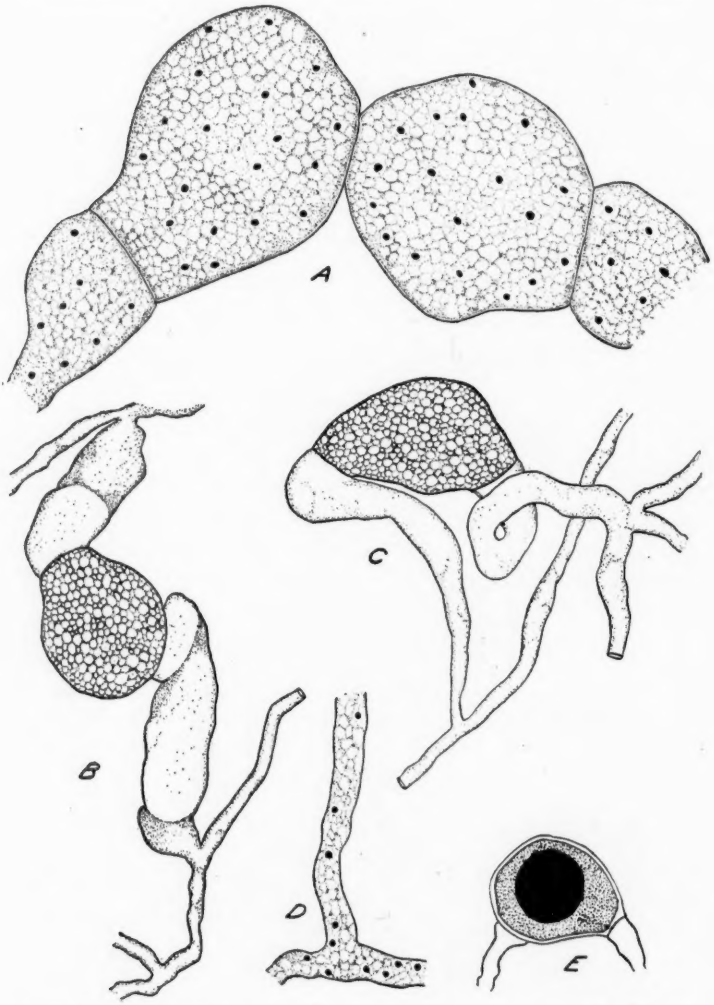

A
B
C
D
E

PLATE 86

Choanephora cucurbitarum:

A.—Gametes prior to fusion. Gametes and suspensors are plurinucleate. ×900.

B.—Young zygospores whose exospore has not yet developed and whose contents are a dense mixture of granular protoplasm and small oil droplets. The origin from two mycelial branches is also shown. ×320.

C.—Lateral view of a young zygospore in the same stage of development as figure B. ×320.

D.—Cœnocytic mycelium. ×900.

E.—Mature zygospore with a well-developed exospore and a large oil globule. ×275.

PLATE 87

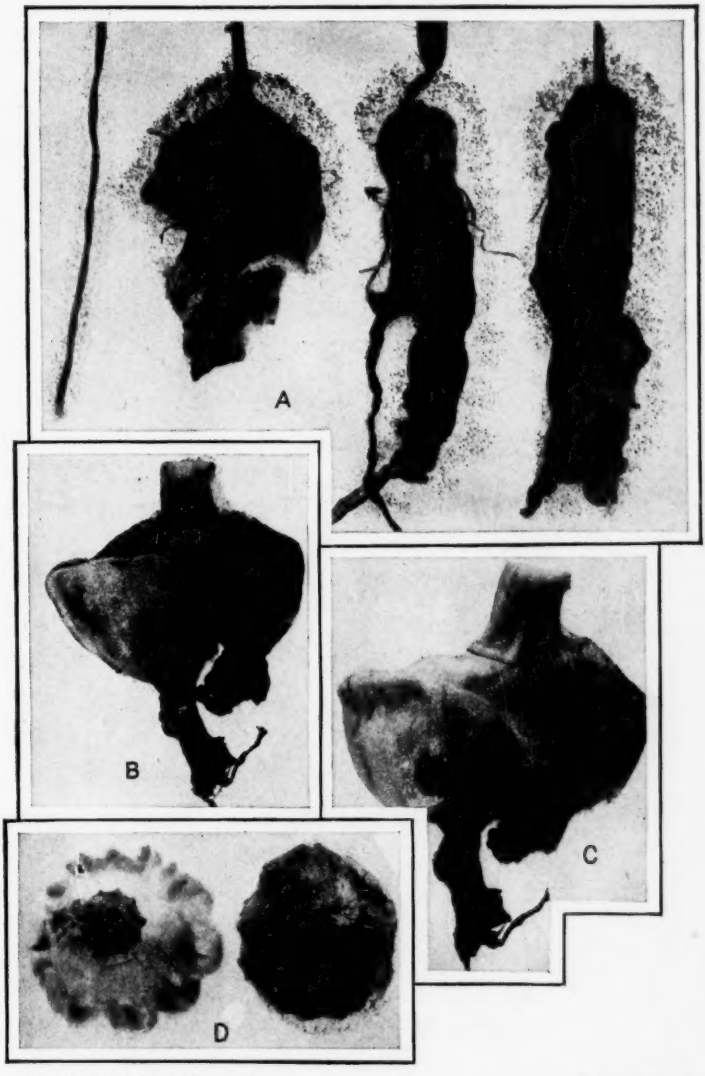
Choanephora cucurbitarum:

A.—Fructifications on squash corollas and flower pedicels. Natural infection.

B.—Natural infection on squash fruit showing the rapidity of the decay when contrasted with figure *C*, which is reproduced from a photograph of the same fruit 15 hours earlier.

C.—A diseased teratological squash.

D.—Infection through the corolla in the fruit at the left and complete decay of the squash at the right.


A
B
C
D

DISCOVERY OF INTERNAL TELIA PRODUCED BY A SPECIES OF CRONARTIUM

By REGINALD H. COLLEY,

Agent, Investigations in Forest Pathology, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

Adams (1)[1] has recently listed the reports of a number of investigators who have found rust sori developing internally in the host tissue. Both Adams (1) and Wolf (7) fail to mention the work of Bolley and Pritchard (2) and Pritchard (5, 6), who made careful studies of internal sori in wheat grains. A review of the literature shows that pycnia, æcia, uredinia, and telia have been found inside the tissue of the host plant, producing what were apparently normal spores. Table I summarizes all the accounts of internal rust sori which are known to the writer.

TABLE I.—*Summary of accounts of internal rust sori*

Author.	Parasite.	Spore stages.	Host.	Where located.
Adams, J. F. (1)...	*Nigredo caryophyllina* (Schrank) Arthur=*Uromyces caryophilinus* (Schroeter).	II	*Dianthus caryophillus* L.	In leaves.
Atkinson, G. F., and Edgerton, C. W. and Reddick, Donald (7).	*Nigredo caladdii* (Schw.) Arthur =*Uromyces caladdii* Farlow.	I	*Peltandra virginicia* (L) Kunth.	(?)
Bolley, Henry L., and Pritchard, F. J. (2).	*Puccinia graminis tritici* E. and H.	II and III.	*Triticum* sp.....	Beneath bran layer and about embryo of seed.
Eriksson, J., and Henning, E. (5)	*Puccinia glumarum* (Schmidt) Eriks. and Henn.	II and III.	Cereal grains....	In pericarp.
Fromme, Fred D. (4).	*Puccinia claytoniata* Peck.	o	*Claytonia virginica* L.	Deep in parenchyma of stem.
Pritchard, F. J. (6).	*Puccinia graminis tritici* E. and H.	III	*Triticum* sp.....	In seed near hilum.
Pritchard, F. J. (5).	*Puccinia graminis tritici* E. and H.	III	.....do.....	In pericarp of wheat grain.
Reddick, Donald (7).	*Puccinia graminis* Pers.	I	*Berberis vulgaris* L.	In fruit.
Do.....	*Dicaeoma poculiforme* (Jacq.) Kuntze = *Puccinia graminis* Pers.	II	*Secale* sp.....	In stem.
Smith, W. G. (5)...	*Puccinia graminis* Pers.	III	*Avena* sp.....	Next to gluten layer of seed.
Wolf, F. A. (7).....	*Puccinia angustata* Peck.	I	*Lycopus virginicus* L.	In pith and parenchyma tissue of petioles and stems.

[1] Reference is made by number to "Literature cited," p. 332.

Journal of Agricultural Research, Washington, D. C.
he

Vol. VIII, No. 9
Feb. 26, 1917
Key No. G—107

A glance at the table shows that practically any part of the host plant may contain internal sori. According to the accounts of different authors, sori were found buried deep in the tissue of the host plants, freeing their spores into hollow stems, or intercellular spaces, and in some cases making room for the lengthening spore chains by forcing aside the surrounding parenchyma cells (Pl. 88, *B*). Of course, the sori in seeds had little room to expand. Fromme (3, 4) has reported odd cases where the pycnium was located in the æcium. The discovery of these internal sori has probably been accidental in all cases, although the investigators may have been looking for abnormal conditions.

OBSERVATIONS ON THE INTERNAL TELIA OF CRONARTIUM RIBICOLA

It will be noted that the fungus genera mentioned in Table I all belong to the Puccinia and Uromyces groups. So far as the writer is aware, there have been no reports of internal sori of any species of the genus Cronartium. In the course of intensive investigations on *Cronartium ribicola* Fisher, the white-pine blister rust, a striking case of the development of internal telia was discovered in the petiole of *Ribes roezli* (Regel) Coville and Britton. The plant was inoculated in July, 1915, and was kept in the greenhouse through the following winter. On February 28, 1916, telia were found by Spaulding [1] on the petiole of one dead leaf and of one partially dead leaf, both still remaining on the plant. These petioles were killed, embedded in paraffin, and sectioned. Close to the base of the leaf the pith and pericycle regions (Pl. 88, *A*) of the petiole were found to be practically stuffed with the mycelium of the parasite, while farther from the leaf base there was less complete destruction of the host tissue. Haustoria, which were larger and more numerous than those in the leaf, suggested that the mycelium was more active in the petiole than in the leaf. At intervals in the tissue of the regions mentioned telia had begun to develop (Pl. 88, *E*). The direction of growth of what would normally be telial columns was very variable, some growing toward the outside, some toward the center of the petiole. Quite naturally the telia could not produce a typical telial column in such cramped quarters, and the variations were such as one would expect; the sori were broadened out (Pl. 88, *D*), the spores compressed, and the columns where partially developed were coiled or bent by the pressure on the free ends (Pl. 88, *C*). Despite the distortion of the columns, the spores quite closely resembled the spores from a normal sorus, lacking, however, in many cases, the heavier brown wall, characteristic of the fully developed spores of an external column. Possibly the walls would have taken on the brown color as the spores matured. In several of the sori, older than the others, the spores were just begin-

[1] Dr. Perley Spaulding, of the Office of Forest Pathology, supplied the material for this study, and kindly furnished the data on the inoculation.

ning to develop the wall thickening and color change. The walls of the spores at the tip of the telial column shown in Plate 88, *C*, were identical in color and thickness with the walls of spores in external columns. The measurements of the internal spores, 10 to 20 by 20 to 40 μ, agreed well with those of normal spores, considering the conditions under which the internal spores were produced. There was at first some doubt as to the true nature of the spores, for some of the sori were surmounted with a peridium like the peridium of a normal uredinium. This would not exclude the possibility that the sorus was a telium, for the normal telial column often arises from an old uredinium. In this case, indeed, there could be no question whether the spores were urediniospores or teliospores, since the mycelium, which, as mentioned above, sometimes stuffed the pith region, was typically binucleate; the spores were uninucleate; and the change from the binucleate condition to the uninucleate condition occurred just after the spores were cut off from the basal cells of the sorus. This cytological evidence, agreeing as it does with cytological conditions in sori producing teliospores, completely established the identity of the internal sori as telia, even when the spores were very young.

The occurrence of the petiole infection is rather common in both wild and cultivated species of Ribes where the general infection is heavy. In two other species examined, *R. nigrum* L. and *R. cynosbati* L., no internal telia had been formed, although the mycelium was abundant and normal telia present on the surface of the petioles. The epidermal region of the petioles of *Ribes* spp. undoubtedly offers more resistance to the developing telia than the epidermis and palisade cells of the leaf. The sori probably are unable to break through the stiffer layer in the petiole; hence, their development as far as possible within the inclosing tissue. Unquestionably internal sori should be regarded as rather common teratological phenomena, developed in spite of their unfavorable position. Morphologically they have no special significance. Their development is to be expected whenever the point at which the sorus begins to form is located beneath a layer of tissue which offers a greater resistance than the developing sorus can overcome. Accidental discovery of the sori after the material had been killed and embedded has precluded any spore germination experiments. Investigators, however, have found the internal mycelium, and the teliospores themselves, to be in a living state after a considerable time, even in comparatively dry tissue. Pritchard (5) figures the teliospores as undergoing a sort of palmella-like division which may be the equivalent of germination. In his material the mycelium was certainly alive for a long time. There is a possibility that the phenomena described by Pritchard (5) might be observed under suitable conditions in the internal teliospores of *Cronartium ribicola*.

SUMMARY

(1) All four types of rust sori have been found developing internally in the host-plant tissue, producing spores which appear quite normal and which fill intercellular spaces or force aside the softer tissue.

(2) The fact that *Cronartium ribicola* Fisher produces internal telia is here reported for the first time. These telia form spores inside the petioles of species of Ribes, chiefly in the pith and pericycle region.

(3) Internal sori should be regarded as rather common teratological phenomena.

LITERATURE CITED

(1) ADAMS, J. F.
1916. Internal uredinia. *In* Mycologia, v. 8, no. 3, p. 181–182, pl. 186.

(2) BOLLEY, H. L., and PRITCHARD, F. J.
1905. Internal infection of the wheat grain by rust—A new observation. *In* Science, n. s. v. 22, no. 559, p. 343–344.

(3) FROMME, F. D.
1912. Sexual fusions in the flax rust. *In* Bul. Torrey Bot. Club., v. 39, no. 3, p. 113–131, pl. 8–9.

(4) ———.
1914. The morphology and cytology of the aecidium cup. *In* Bot. Gaz., v. 58, no. 1, p. 1–35, 8 fig., pl. 1–2.

(5) PRITCHARD, F. J.
1911. A preliminary report on the yearly origin and dissemination of Puccinia graminis. *In* Bot. Gaz., v. 52, no. 3, p. 169–192. pl. 4.
Cites W. J. Smith (p. 173).

(6). ———.
1911. The wintering of Puccinia graminis tritici E. and H. and the infection of wheat thru the seed. *In* Phytopathology, v. 1, no. 5, p. 150–154. 2 fig., pl. 22.

(7) WOLF, F. A.
1913. Internal aecia. *In* Mycologia, v. 5, no. 6, p. 303–304, pl. 111.

74552°—17——2

PLATE 88

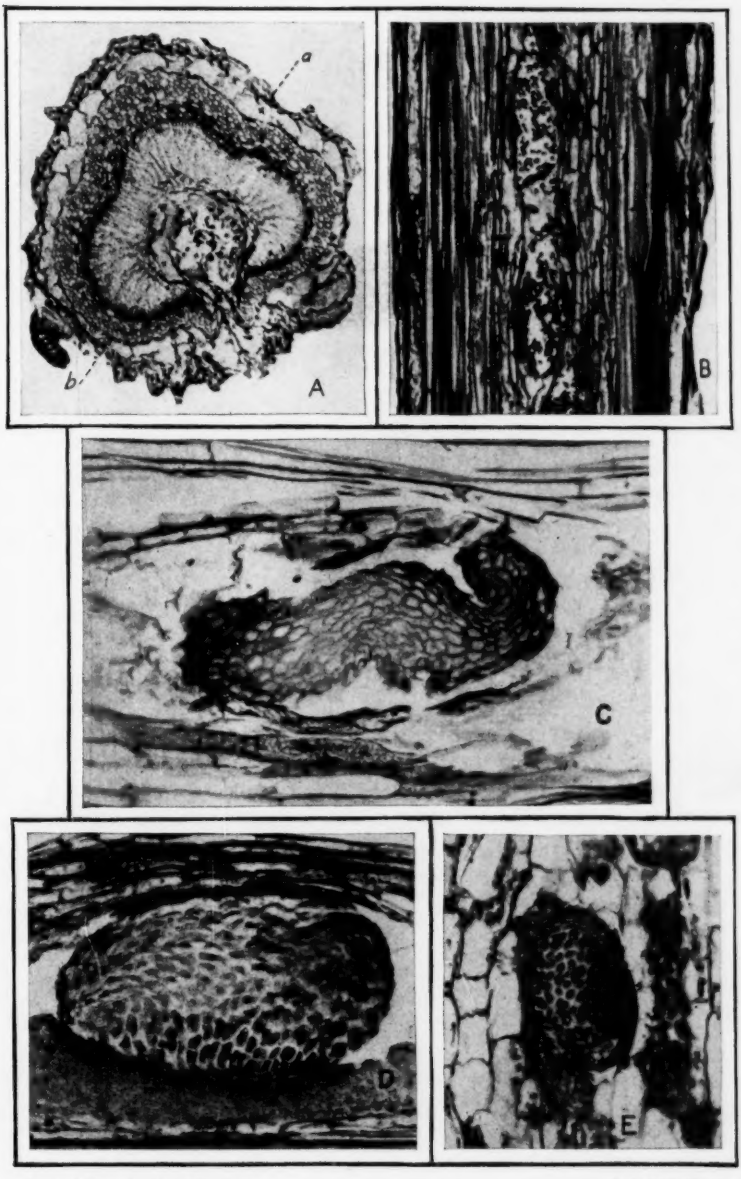
A.—Cross section of a petiole of *Ribes roezli*, showing the pericycle (*a*) and pith (*b*) regions which are stuffed with the mycelium of *Cronartium ribicola*. Most of the pith cells have been destroyed. Teliospores partially fill the cavity.

B.—Longitudinal section of the same petiole, showing the manner in which the sori force aside the parenchyma cells of the pith.

C.—Internal telium of *Cronartium ribicola* from the pericycle region of a petiole of *Ribes roezli*. The telium has been forced to coil on account of the pressure of the surrounding cells.

D.—Internal telium of *Cronartium ribicola* from the pericycle region of a petiole of *Ribes roezli* flattened by pressure.

E.—Young internal telium of *Cronartium ribicola* from the center of the pith region of a petiole of *Ribes roezli*, illustrating the depth at which sori may start to develop.


a
b
A
B
C
D
E

EFFECT OF IRRIGATION WATER AND MANURE ON THE NITRATES AND TOTAL SOLUBLE SALTS OF THE SOIL

F. S. HARRIS, *Director and Agronomist*, and N. I. BUTT, *Assistant Agronomist*,
Utah Agricultural Experiment Station

INTRODUCTION

Plants obtain their food from the soluble salts of the soil; therefore the study of these salts is of great importance to agriculture. There is no method available for measuring exactly what portion of the plant food in the soil can be taken up by crops at any given time; the nearest approach is to extract the soil with some solvent and to determine the quantity of plant food in the solute.

Imperfect as this method is in approximating the available plant food, it yields many valuable data which help to an understanding of some of the complex soil changes.

In the present paper an attempt has been made to determine the effect of varying quantities of soil moisture and manure on the total soluble salts and nitrates that can be extracted by water from the soil. Some of the soils under investigation were kept in the laboratory, others were allowed to stand for long periods in large tanks, while still others were studied under normal field conditions. Comparisons were also made of cropped with uncropped soils in tanks and in the field.

REVIEW OF LITERATURE

Most of the former work on the soluble salts of the soil has been done in humid climates, where conditions are different from those under which the experiments herein reported were conducted. For this reason there is not a complete agreement in the results.

King (8, p. 92–107)[1] found that the ratio of total soluble salts to nitrates varied between 2.14 to 1 and 9.97 to 1 under different conditions. The total soluble salts, and especially the nitrates, were higher in fallow than in cropped soils; and crops used the nitrates faster than they did the other soluble salts.

Investigations by Stewart and Greaves (13, 14) show the application of irrigation water to have a distinct beneficial effect on nitrate formation, being greatest where 15 inches of water were applied. In cropped land there was less nitrogen in the soil during the fall and spring than during the summer. More nitrogen was found in fallow ground in the fall than in the spring, but most of the surplus disappeared during the

[1] Reference is made by number to "Literature cited," p. 359.

Journal of Agricultural Research. Vol. VIII, No. 9
[Dept. of Agriculture, Washington, D. C. Feb. 26, 1917
hi Utah—5

winter. The concentration of the soil solution was higher in fallow soil than in that producing alfalfa, oats, or corn, and nearly always greater in unirrigated than in irrigated soil. It varied widely not only with the crop grown and the amount of water applied but also with depth of soil. There was always a larger amount of nitric nitrogen in fallow plants than in cropped ones, but when the quantity removed by the crop was considered more nitric nitrogen was found in the cropped soil. The amount of nitric nitrogen was more constant in uncropped than in cropped plots and it was found to be comparatively constant in the lower sections of the soil, irrespective of the quantity of water supplied, up to 25 inches.

Contrary to the results of Stewart and Greaves, Russell (12) found that during late summer and early autumn the nitrate content in fallow was higher than in cropped land, even after adding the nitrate taken up by the crop. In a semiarid soil Jensen (4) found no direct relationship between moisture and nitrates. He later (5) found that an irrigation, followed by a heavy rain, evidently diminished the nitrates. More nitrates were found in summer-fallowed than in cropped soil. The average quantity of total nitrogen for the season showed no evident correlation with the quantity of nitrate nitrogen found. Control plots showed slightly more nitrates than those receiving either dry-yard or composted manure, but the reverse was true of the fallow plots.

In a humid climate Weis (17) found no relationship between the percentage of moisture and the nitrate production. King (7) found the same, and also that there is a lack of correlation between nitrates and crop yield.

Watt (16), in South Africa, observed that manure, cultivation, and increased moisture served to raise the nitrate content. That manuring the soil with dung very slightly increased the amount of nitrates was among the observations of Tulaikov (15) in Russia. The depth to which regularly cultivated fallow land was plowed had little influence on the accumulation of nitrates. He also found that the accumulation of nitrates in the soil, under conditions obtaining in the black soil regions of Russia, was much facilitated by the fact that all measures taken to accumulate water in the soil accelerated the accumulation.

McIntyre (11), in reporting the results of 30 years' use of barnyard manure, concluded that soils receiving 6 and 10 tons of manure were practically identical in nitrate content, while the soil that received 8 tons was lowest.

At Cornell University the application of 20 tons of farm manure to the acre to sod on a clay loam soil for three years resulted in a larger production of nitrates on the manured soil than on adjoining unmanured soil.

The work of Johansson (6) showed a close relation between the amount and movement of the soil water and the distribution of nitrates in a heavy clay soil. The nitrates were carried downward by the rain water and

later moved upward as the water was evaporated from the surface of the soil.

For a humid soil Hall (3, p. 230) showed that no more nitrates were leached from a 60-inch lysimeter at Rothamsted than from one 40 inches deep, from which it was concluded that nitrification does not take place below 40 inches from the surface.

Buckman (1) has shown that under dry-farm conditions the formation of nitrates is greater where there is a good supply of soil moisture than where the soil is dry. Intertilled crops after fallow did not seriously deplete the soil for the succeeding grain crop, either in moisture or in nitrates.

Lyon and Bizzell (10), as well as other experimenters, found the formation of nitrates to be influenced by the crop growing in the soil.

At the Rothamsted Experiment Farm (9) nitrates were found to increase, evidently from better moisture conditions, in the fall after a heavy rainfall.

A report of the Washington Agricultural Experiment Station (2, p. 17–18) shows a tendency for the larger quantities of nitrates to be formed in the upper foot of the soil and the smaller quantities deeper, down to 36 inches (the lowest depth analyzed); but there were a greater number of high-nitrate samples below 20 inches than above. The highest nitrate content was found in the spring before the plants began to grow.

EXPERIMENTAL WORK

METHODS OF ANALYSIS

In determining the total soluble salts and nitrates 100 gm. of freshly sampled soil were used. To this, 500 c. c. of distilled water were added and stirred thoroughly, then allowed to settle for 20 minutes, after which it was filtered through a Chamberland-Pasteur filter, the first 100 c. c. of the filtrate being discarded.

To get the total salts, 100 c. c. of the filtrate were evaporated to dryness on a steam bath and the residue weighed. The nitrates were determined by the colorimetric method described by Schreiner and Failyer.[1] Both the nitrates and the total salts are expressed in parts per million of dry soil.

SOIL CHANGES IN GLASS JARS

The first experiment was conducted in the laboratory, the object being to study the influence of different quantities of moisture on soil changes under controlled conditions. Glass jars holding 800 gm. of dry soil were made up to percentages of water from 2.95 to 54.47, with differences of about 5 per cent. These were loosely covered with lids to

[1] Schreiner, Oswald, and Failyer, G. H. Colorimetric, turbidity, and titration methods used in soil investigations. U. S. Dept. Agr., Bur. Soils Bul. 31, p. 39-41. 1906.

reduce evaporation, although air could circulate freely. The percentages of moisture were maintained by replacing the water lost at the end of each month. The soil was a sod and was pulverized and sieved before being placed in the jars. An analysis of the soil was made after it had been held under the treatment from January, 1912, to August, 1914.

The results are given in figure 1, which shows the largest amount of total soluble salts in the soil kept at nearly 29 per cent moisture. As the soil moisture increased beyond this amount there was a sharp decrease of soluble salts present.

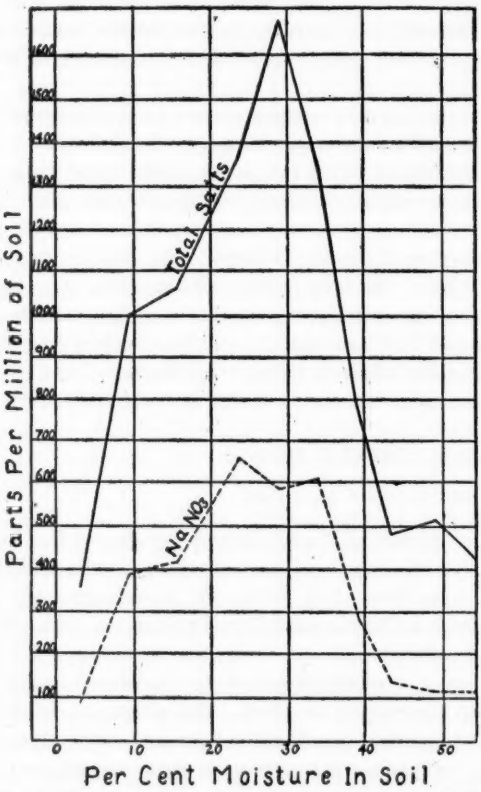


FIG. 1.—Graph showing the total soluble salts and nitrates in soil held in the laboratory, with different quantities of moisture for 2½ years.

The nitrates varied much the same as did the total salts, the main difference being that the maximum quantity of nitrates was found with an initial soil-moisture content of about 24 per cent. It must be remembered that the soil dried out somewhat between waterings; hence, the average moisture would be a little below this amount. The most rapid rise occurred practically at the same places for nitrates and total salts, and the two curves followed each other rather closely. This seems to indicate that the rise in total salts is due largely to the nitrates. Should the nitrates in the soil be considered as $NaNO_3$, the increase, using the lowest percentage as the basis of comparison, will account for nearly half of the increase in total salts. The ratio of total salts to nitrates decreases from 4.34 to 1 at 2.95 per cent moisture to 2.09 to 1 at 23.55 per cent, and then rises to 4.31 to 1 at 48.3 per cent.

These results indicate that in a soil of the nature used in this experiment a moisture content between 23 and 28 per cent is the most advantageous for liberating plant food, especially for the formation of nitrates.

VEGETATION-HOUSE RESULTS

From an experiment begun in 1913 to study the effect of various moisture treatments on the growth of wheat under controlled conditions, samples were taken for the second part of this report. Galvanized-iron tanks, 2½ feet high and 2 feet in diameter, filled with a fertile loam soil containing a high percentage of magnesium and calcium carbonate, were used in this experiment. This is not the same soil as that used in the laboratory study. Enough New Zealand wheat was planted in each tank to make sure of an even distribution of 30 plants in each cropped pot. A half-inch layer of clean sand, covered with paraffined paper, was put over the top of each pot after the plants were up, to reduce water loss by evaporation.

These tanks were placed in groups of six on low cars in an inclosure, 26 by 54 feet, protected on the north and east by board fences 10 feet high. When weighings were to be made, the cars were wheeled beneath a large steelyard and each tank raised from the car by means of hooks attached to the steelyard. The weighings were accurate to 1 pound.

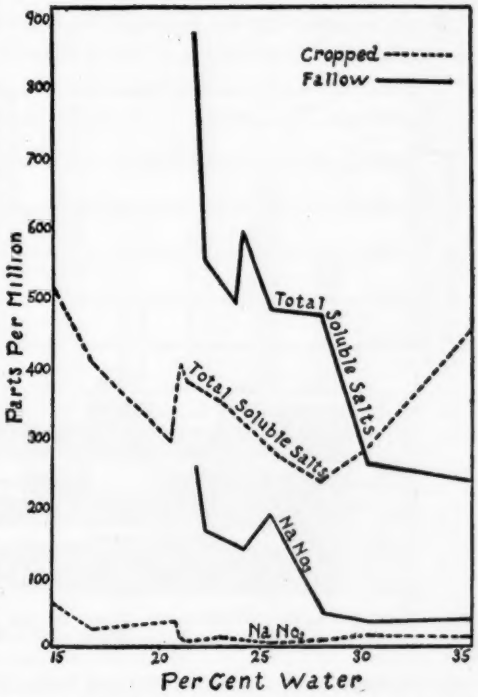


FIG. 2.—Graph showing the total soluble salts and nitrates in cropped and fallow soil maintained at various moisture contents in large tanks.

Twenty tanks were kept at a uniform moisture content throughout the season, one of each treatment being fallow and one cropped each year. Nine other tanks were used, in which the moisture given the plants varied with the stage of growth. The first stage included the period until the plants had five leaves, or until about the last of June; the second from this time until the plants were in the boot just ready to head; and the third from the boot stage to maturity, which usually occurred about the middle of August.

In 1914 and 1915, samples of the soil were taken from each of the tanks after the crop was harvested, and determinations made of total

salts and nitrates to the full depth of the tanks. Each sample was thoroughly mixed before the analysis was made; hence, the figures represent the average for the whole tank. There was a check tank for each treatment.

CONSTANT-MOISTURE CONTENT

The lowest moisture content was a little less than 15 per cent for the cropped and nearly 22 per cent for the fallow tanks, and the highest slightly over 35 per cent for both sets that were maintained at the same moisture content throughout the season.

Figure 2 shows that the lowest moisture content favored the greatest accumulation of total soluble salts and nitrates in both the cropped and

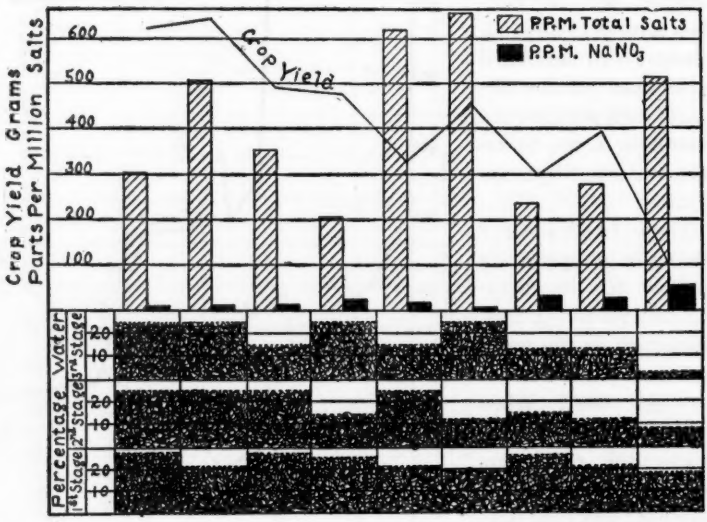


FIG. 3.—Graph showing the total soluble salts, nitrates, and crop yields in tanks containing soil with varying moisture contents during different stages in the growth of the crop.

the uncropped soils. For the cropped tanks containing between 20 and 28 per cent of moisture (where the best crop growth was obtained) the total salts and nitrates, as compared with fallow, are especially low.

The fallow tanks decreased in total salts from 874 parts per million at a moisture content of about 22 per cent to 235 p. p. m. at slightly over 35 per cent. Corresponding to these moistures, the nitrates decreased from 250.9 to 35.8 p. p. m. It will be noted that the ratio of total salts to nitrates is much larger for the cropped than for the fallow plots, showing that the plants take up nitrates faster than they do the other salts.

VARIATION IN MOISTURE AT DIFFERENT STAGES

Figure 3 shows the percentage moisture maintained in the second set of tanks for each stage in the growth of wheat, the total salts and

nitrates found in the soil after the crop had been harvested, and the total yield of grain and straw. The moisture treatments in the illustration have been so arranged that the amount of water in the soil decreases from left to right.

The total salts do not seem to vary consistently with any of the other determinations shown. In general, however, the nitrates vary inversely as the percentage soil moisture and the crop yield, the crop yields standing somewhat in proportion to the total amount of water for the season in the tanks. The variations are thought to be due largely to changes in soil-moisture content at the different stages.

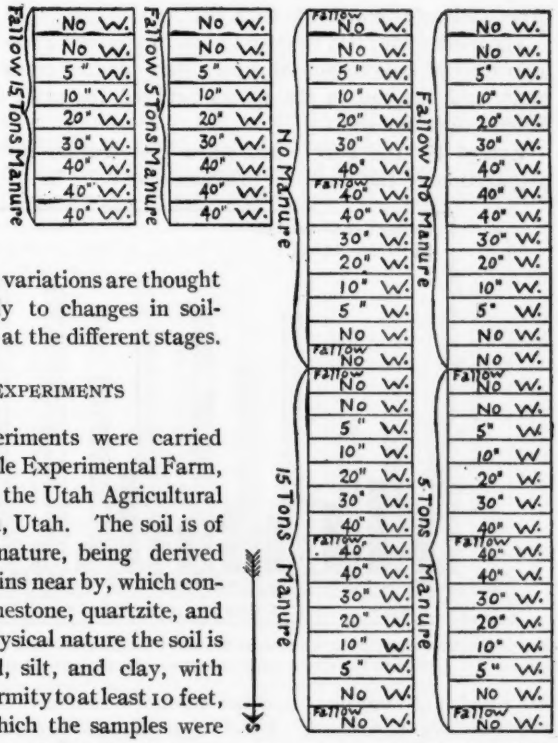


FIG. 4.—Arrangement and treatment of plots in field experiment.

FIELD EXPERIMENTS

The field experiments were carried on at the Greenville Experimental Farm, 2 miles north of the Utah Agricultural College, at Logan, Utah. The soil is of a sedimentary nature, being derived from the mountains near by, which consist largely of limestone, quartzite, and dolomite. In physical nature the soil is mostly fine sand, silt, and clay, with remarkable uniformity to at least 10 feet, the depth to which the samples were taken. The soil contains about 43 per cent of calcium and magnesium carbonates and is rich in all the essential plant-food elements with the exception of nitrogen. The plots had received no manure for many years before the experiment was begun. A more detailed description of the soil and conditions of the farm have been published by the Utah Station.[1]

Figure 4 shows the arrangement of the plots and the treatments received. There were 12 cropped and 18 fallow plots unmanured, 12 cropped and 12 fallow manured at the rate of 5 tons, and 12 cropped and 12 fallow manured at the rate of 15 tons to the acre.

[1] Widtsoe, J. A., and McLaughlin, W. W. The movement of water in irrigated soils. Utah Agr. Exp. Sta. Bul. 115, p. 197–268, illus. 1912.

In each manuring treatment two cropped plots received each of the following quantities of irrigation water: None, 5, 10, 20, 30, and 40 inches. This gave 6 cropped plots for each irrigation treatment. Besides the cropped soils, 6 plots receiving no water, 4 with 40 inches, and 2 of each of the other irrigated, unmanured plots were left fallow. Each of the manured, fallow series contained 4 plots unirrigated and 4 irrigated at the rate of 40 inches, together with one plot for each of the other moisture treatments each year.

The plots were 7 feet wide and 24 feet long, with 4 feet of space between. Two rows of Dakota Sunshine corn were planted on each of the cropped plots, and one row in the spaces between the plots to make the conditions more uniform.

Except for the year 1912, when the weather prevented the usual preparation of the land, the plowing was done in the fall and the soil

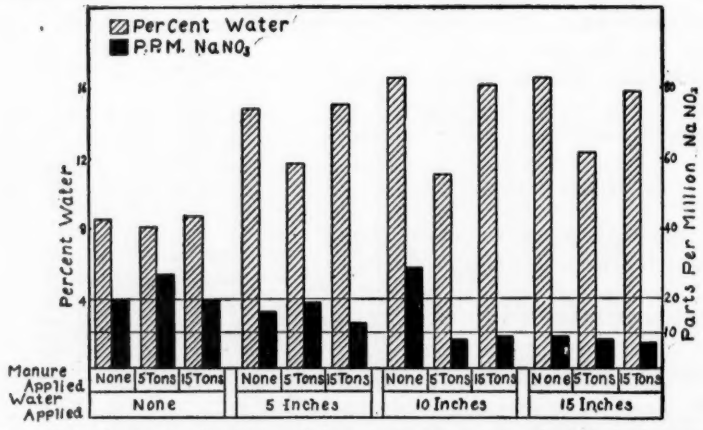


FIG. 5.—Graph showing the soil moisture and nitrates on August 7, 1911, to a depth of 3 feet in cropped soil to which different quantities of water and manure had been added.

left rough until spring, when the manure was added to the plots which received this treatment. Later, the manure (mixed horse and cow manure, fairly well rotted) was thoroughly disked or plowed into the land.

The water was distributed from wooden flumes as follows: For plots receiving 5 inches, 2½ inches each at the beginning of tasseling and at roasting-ear stage; plots receiving 10 inches, 5 inches at each of the above two stages; plots receiving 20 inches, 5 inches each when the plants were 12 inches high, at the beginning of tassel, at bloom, and at roasting-ear stage; plots receiving 30 inches, 5 inches each when plants were 12 inches high, 10 days later, at beginning of tassel, at bloom, at roasting-ear stage, and 10 days later; and plots receiving 40 inches, applications of 5 inches when plants were 12 inches high, and this amount each week thereafter until all water was added. The fallow plots were irrigated at the same time as the cropped.

The experiment was begun in 1911, but only results with the nitrate and moisture content of the soils for the midseason period were taken during that year. No determinations were made in 1912, but mid-summer data for 1913 and complete results for the fall seasons of 1913, 1914, and 1915 are included. As the season of the year is thought to influence the production of nitrates to quite an extent and because the water applied, as well as the depths sampled, varied, the two preliminary trials are considered separately.

Preliminary Tests

Summer of 1911

The samples taken on August 7, 1911, include only the first 3 feet of soil at a time when the most water applied on any plot was 15 inches.

Figures 5 and 6 give the average moisture and nitrates to a depth of 3 feet, figure 5 representing the cropped and figure 6 the uncropped plots.

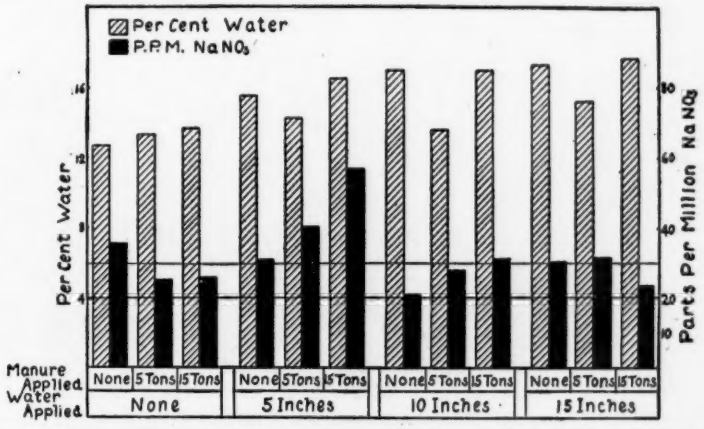


Fig. 6.—Graph showing the soil moisture and nitrates on August 7, 1911, to a depth of 3 feet in fallow soil to which different quantities of water and manure had been applied.

On an average the cropped plots receiving no manure contained more water than those receiving either 5 or 15 tons, and the difference is most noticeable with the larger applications of irrigation water. In depth the first foot of the 15-ton-of-manure plots contained more water than those with no manure, and the first foot of the 5-ton plots proportionately more than the other feet when compared with the unmanured. For these 3 feet the moisture increased with the depth of soil. The land receiving manure at the rate of 5 tons contained an average of about 3 per cent less water than that receiving none or 15 tons, and was more than this for the larger quantities of water applied.

While the nitrates in the cropped plots to which 5 tons of manure were added were higher than those receiving none, where no water and 5 inches of water had been applied, the average for the unmanured plots was higher than that of either of the manurial treatment soils. The third foot of the three treatments differed little.

In general, the nitrates in the first 3 feet vary inversely with the water applied.

The moisture content of the fallow plots receiving manure at the rate of 15 tons to the acre averages highest, the unmanured slightly lower, mainly in the third foot, and those on which 5 tons were applied considerably below the two others, especially for the larger irrigations.

With 15 tons of manure the average nitrate content of the soil was highest, and with no manure lowest, these differences occurring mostly with 5 and 10 inches of water. The nitrates of the manured plots show a rather marked rise when a 5-inch application of water had been used, while more than this amount causes a decrease. A tendency for a steady decrease of nitrates with increasing percentages of water was not noticed in the fallow plots as it was in the cropped.

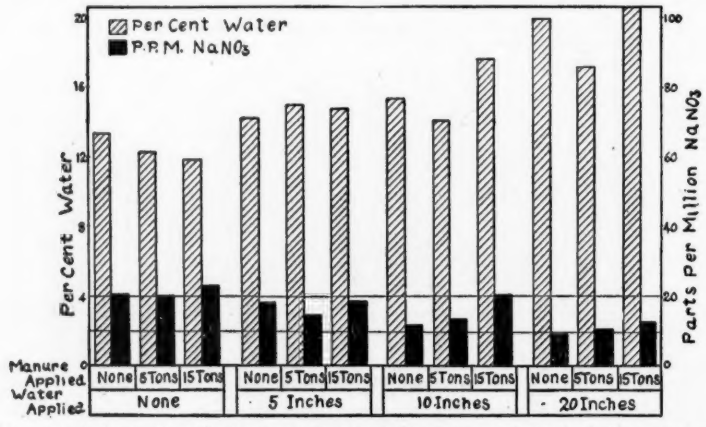


FIG. 7.—Graph showing the soil moisture and nitrates on July 21, 1913, to a depth of 10 feet in cropped soil to which different quantities of water and manure had been added.

Comparing cropped and fallow plots, we find that comparatively more of the nitrates are used by the plants on the 15-ton-of-manure soil than on the 5-ton, and more on the 5-ton than on the unmanured. For the 3 feet shown the difference in nitrates between fallow and cropped soil decreases with increasing depth. Except for the unirrigated soil the nitrates, as shown at this part of the season, are influenced much more by the crop than is the percentage water. The cropped soil contained on the average approximately 15.3 p. p. m. of nitrates, expressed as sodium nitrate ($NaNO_3$), and the fallow a little more than double this quantity.

SUMMER OF 1913

On July 21, 1913, the plots were again sampled, this time to a depth of 10 feet. The moisture and nitrates for all cropped plots are shown in figure 7, and for all fallow plots in figure 8. These results show that 5

tons of manure reduced the moisture content of the cropped soil, and only slightly affected the nitrates, while 15 tons increased both the moisture and nitrates, especially for the larger applications of water.

For 5 and 10 inches of irrigation water, when averaged for all manurings, the increase in moisture content due to irrigation was more rapid in the top few feet than below; but for 20 inches the increase was rather uniform throughout the entire 10 feet. Although the nitrates were proportionately higher in the unirrigated plots at medium depths, the decrease in nitrates for increasing amounts of water was shown more in the top few feet than at the greater depths.

In the fallow plots the highest percentage of moisture, on an average, was found under a manuring of 15 tons, and the least with no manure, but the differences were not great. The nitrates were also lower in the

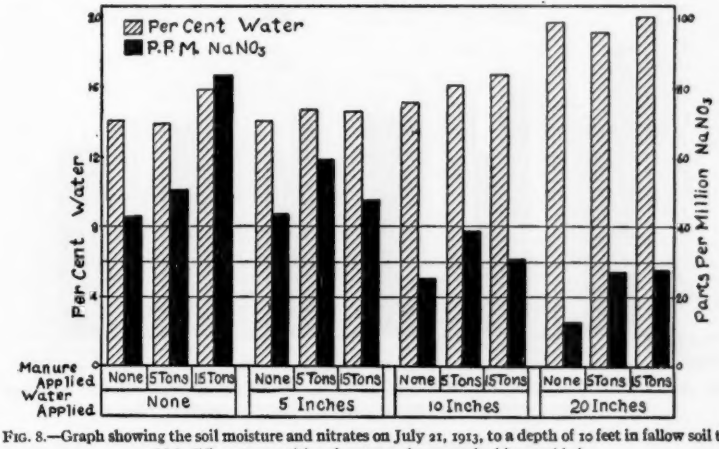


FIG. 8.—Graph showing the soil moisture and nitrates on July 21, 1913, to a depth of 10 feet in fallow soil to which different quantities of water and manure had been added.

unmanured than in the manured land. The larger manuring was usually the more beneficial to the production of nitrates, especially in the unirrigated land, although the 5-ton-per-acre plots contained somewhat larger amounts for 5 and 10 inches of water applied than the 15. The decrease in nitrates for increasing irrigations was rather marked.

At this stage of growth practically the only difference in the moisture content between cropped and fallow plots is the greater loss on the cropped plots receiving no water, especially on the manured land. In a general way the nitrates of both cropped and fallow soils decrease with increasing amounts of irrigation water. The fallow plots show the effect of the increasing quantities of water more than do the cropped, and the influence is felt to greater depths in the fallow soils.

The effect of cropping on nitrates was much greater for soils receiving manure, and especially where the amount of irrigation water applied

was small. This last is most notable in the first and again in the middle to lower depths of sampling. The cropped plots averaged 16.4 p. p. m. and the fallow 40.6 p. p. m. of sodium nitrate.

AVERAGES FOR THE FALL SEASONS OF 1913, 1914, AND 1915

TOTAL SOLUBLE SALTS IN CROPPED SOIL

From Table I and figure 9, which show the total soluble salts found in the cropped plots to a depth of 10 feet about the first of September, just after the corn crop had been removed, we find that with a slight exception on the lands receiving 10 inches of water, manuring with 5 tons per acre resulted in a lower salt content than with no manure. This difference is most marked with no and 5 inches of water applied,

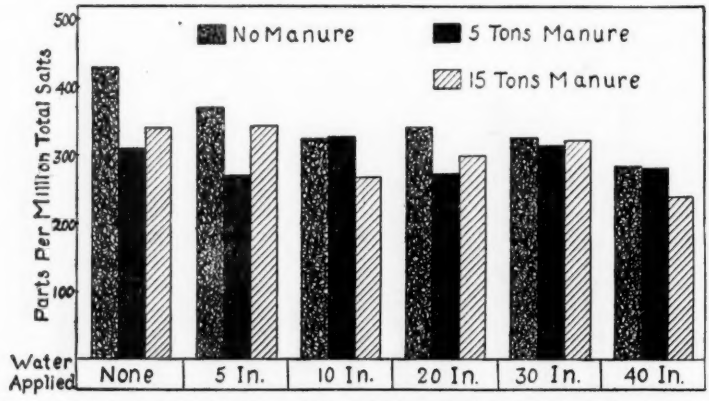


FIG. 9.—Graph showing the total soluble salts in the fall in cropped soil receiving different quantities of manure and irrigation water. Average of 3 years to a depth of 10 feet.

and with 10, 30, and 40 inches is hardly noticeable. In depth, although there are quite a number of exceptions for the individual feet in the irrigation treatments, the average shows a difference in total salts favoring no manure. The greatest variation is at the fifth, sixth, and seventh feet, and least at the first and ninth feet.

Plots receiving 15 tons of manure showed less total salts for every irrigation treatment than those receiving none. The lower feet of the plots receiving these two treatments show more variation than the upper ones.

It is mainly for no water and 5 inches, and the first, second, third, and sixth feet in depth that the averages for the 15-ton plots exceed the 5-ton plots.

The salts of the cropped soil receiving no manure tend to vary inversely with the water applied; with 5 tons practically no regular variation is shown, while 15 tons indicates an irregular variation inversely with the water applied. The average for all manuring treatments,

therefore, shows a tendency for an inverse variation, the difference between the plots receiving no water and those receiving 40 inches being 90 parts per million.

TABLE I.—*Total soluble salts (in parts per million) in the fall at various depths in cropped and fallow soil receiving different quantities of manure and irrigation water. Average for three years*

CROPPED SOIL

Depth of soil.	Soluble salts (p. p. m.).																			
	No water.			5 inches of water.			10 inches of water.			20 inches of water.			30 inches of water.			40 inches of water.			Average.
Manure applied (tons).....	0	5	15	0	5	15	0	5	15	0	5	15	0	5	15	0	5	15	0	5	15	
Feet.																				
1.....	341	304	322	372	288	404	361	372	267	335	234	393	291	300	389	280	314	270	324
2.....	517	325	388	436	318	385	386	337	299	347	228	360	308	402	375	274	238	228	342
3.....	506	319	351	271	283	377	412	386	302	375	298	355	284	275	436	266	356	288	341
4.....	435	416	380	425	259	344	344	303	363	354	309	298	317	300	235	244	271	263	326
5.....	477	283	310	261	226	299	324	287	273	358	260	252	369	282	244	223	218	205	286
6.....	374	247	304	294	260	359	256	253	237	345	300	249	386	286	338	268	278	227	292
7.....	514	278	343	361	238	285	287	348	211	355	232	258	325	322	358	365	277	183	308
8.....	365	353	360	487	267	359	322	342	278	296	282	296	318	284	306	314	333	238	322
9.....	428	294	347	318	314	314	303	357	198	335	304	273	365	361	234	299	262	255	309
10.....	348	271	301	390	247	324	249	296	252	306	279	254	302	314	269	322	290	243	292
Average.....	431	309	340	361	270	345	324	328	268	341	273	298	326	313	322	285	284	240	314

FALLOW SOIL

1.....	455	420	317	432	306	532	469	517	319	440	577	331	487	710	405	284	442	266	428
2.....	382	465	437	365	320	443	381	425	321	518	341	318	536	519	365	324	501	222	399
3.....	285	393	430	412	454	407	381	428	316	452	420	328	403	396	372	315	353	271	379
4.....	484	383	474	444	324	448	374	483	454	366	456	289	460	397	326	292	253	229	385
5.....	356	349	451	427	324	411	364	366	306	357	444	372	361	332	480	304	580	282	381
6.....	401	360	339	389	362	368	397	402	306	435	511	446	354	422	401	297	300	229	377
7.....	335	353	360	362	296	341	397	347	282	388	389	396	359	367	444	334	257	210	345
8.....	355	289	398	322	281	323	362	425	284	316	429	319	384	391	311	322	301	320	341
9.....	396	427	287	442	324	304	278	346	273	342	250	302	362	313	447	299	299	352	336
10.....	335	265	306	433	266	290	266	316	347	353	393	272	378	339	375	290	307	281	323
Average.....	385	370	380	402	326	387	367	405	321	397	421	337	409	419	393	306	359	266	369

In general, it will be noticed that the plots receiving no water contained more total salts in every foot, except the first, than the other treatments. When more than 10 inches of water were applied, the salt content of the top foot of the unirrigated soil was practically equal to or greater than the same foot of those receiving water. The top 2 and the lower 3 feet of the plots receiving 5 inches of water contain more salts than the corresponding feet of the other irrigated plots. When 20 inches were applied, some of the salts seem to have moved below 10 feet; the 30-inch irrigation shows this tendency still more, while the 40-inch application seems to have driven much of the salts below the depths of sampling, since every foot of this treatment is somewhat below the others. Especially is this true for the first 5 feet. In general, the first 4 feet of the first four irrigation treatments are noticeably higher than the feet below, while for the last two irrigations the differences are somewhat more evenly distributed throughout for depth.

TOTAL SOLUBLE SALTS IN FALLOW SOIL

As shown in Table I and figure 10, the total salt content of the fallow soil receiving 5 tons of manure was greater with irrigations of 10 inches or more than where none was applied; but with no or only 5 inches of water the salt content was higher where no manure was added. In most of the upper feet the average salts for the 5-ton-of-manure plots exceeded that with no manure, but the differences are in most cases not very striking.

For every moisture treatment the salt content of the plots receiving 15 tons of manure was lower than where no manure was added, but the difference is not marked where no water was applied. The fifth foot is the only depth at which the salt content of the 15-ton application ex-

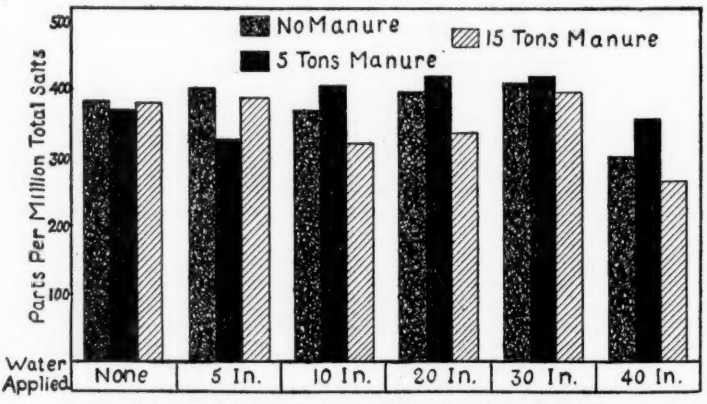


FIG. 10.—Graph showing the total soluble salts in the fall in fallow soil receiving different quantities of manure and irrigation water. Average of 3 years to a depth of 10 feet.

ceeded that of no manure, and the upper feet differed more than the lower.

With no water and 5 inches of water, especially with the latter, the total salts under the plots receiving 15 tons of manure exceeded those with 5 tons, but the other irrigation treatments show quite a wide margin (26 to 93 p. p. m.) in favor of the 5 tons of manure. With regard to depth, the difference in favor of the 5-ton application is mainly in the first 3 feet, the approach being quite gradual from a difference of 133 p. p. m. at the first to 13 at the fourth foot.

The average total salt content of plots receiving 30 inches of water is higher than for the other treatments, especially for the first and second foot in depth. In every foot except the fifth the 40-inch application resulted in a much lower salt content than did the other treatments, and in this exception the difference is not great.

The tendency for the salts to decrease with depth is much more marked in the fallow plots than in the cropped, although with no water and 40 inches for the fallow soil the tendency is hardly noticeable.

As an average the difference in total salt content between fallow and cropped soils was least noticeable on the unirrigated plots and increased with the water applied up to 30 inches. Only 41 p. p. m. more salts were in the fallow than in the cropped soil for an application of 40 inches of irrigation water. The fallow plots differ from the cropped more where the manuring was 5 tons to the acre than for the other treatments. The difference is also more pronounced for the top feet than for the lower ones with applications of no manure and 5 tons, although for 15 tons the lower feet of the two treatments differ most.

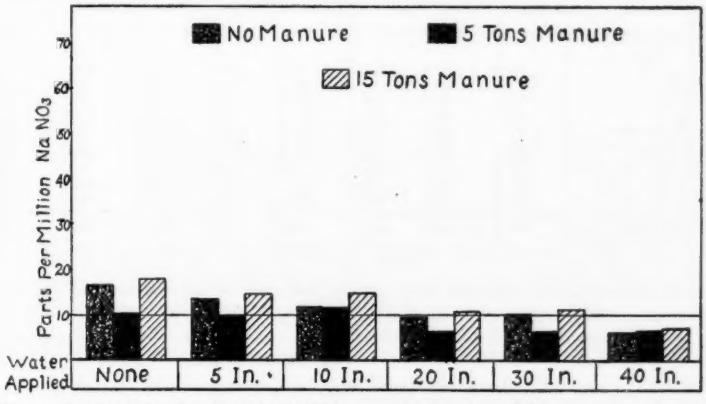


FIG. 11.—Graph showing the nitrates in the fall in cropped soil receiving different quantities of manure and irrigation water. Average of 3 years to a depth of 10 feet.

For most irrigation treatments the total soluble salts in the top foot of the cropped and fallow soils differed considerably more than the average for all feet. This is much more noticeable for the plots receiving 30 inches than for the others both in the first and second foot.

Tables II and III summarize the effects on soluble salts of manure and moisture separately in both cropped and fallow soil.

NITRATES IN CROPPED SOIL

The nitrates, expressed as sodium nitrate in parts per million of dry soil, found in the same plots as discussed above, are shown in Table IV and figures 11 and 12.

Only when the application of water was 40 inches did the nitrates of the cropped plots receiving 5 tons of manure exceed those of unmanured plots, and in this case the difference was small. The greatest variation between the two was for no water. Although the greatest average

difference in nitrates was only about 6 p. p. m., in favor of the unmanured soil, all but the tenth foot in depth show a variation in the same direction.

Manuring with 15 tons to the acre resulted in the formation of over 1.6 p. p. m. more nitrates than where no manure was applied. On the average, the first and third feet in depth are the only ones that this manuring caused to differ noticeably in nitrates.

TABLE II.—*Effect of manure on the total soluble salts in cropped and fallow soil. Average of all moisture treatments for three years*

Depth of soil.	Soluble salts (p. p. m.).							
	No manure.		5 tons of manure.		15 tons of manure.		Average.	
	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.
Feet.								
1	330	426	302	495	341	362	324	428
2	378	418	308	428	339	351	342	399
3	352	375	319	408	351	354	341	379
4	353	403	310	383	313	370	325	385
5	336	358	260	399	263	384	286	380
6	321	389	271	393	286	348	292	377
7	368	362	282	335	273	339	308	345
8	347	344	310	353	306	326	321	342
9	341	354	315	327	276	328	311	336
10	319	343	280	314	274	312	291	323
Average	345	377	296	384	302	347	314	369

TABLE III.—*Effect of irrigation water on the total soluble salts in cropped and uncropped soil. Average of all manure treatments for three years*

Depth of soil.	Soluble salts (p. p. m.).													
	No water.		5 inches of water.		10 inches of water.		20 inches of water.		30 inches of water.		40 inches of water.		Average.	
	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.
Feet.														
1	322	397	355	420	334	435	321	449	327	534	288	331	325	428
2	410	428	380	376	341	376	312	392	362	473	247	349	342	399
3	392	369	310	424	367	386	342	400	332	390	303	313	341	380
4	410	447	343	405	336	437	320	370	284	395	248	258	324	385
5	356	385	262	387	294	346	290	391	298	391	216	388	285	381
6	308	387	305	373	249	369	298	464	337	392	258	275	293	377
7	378	349	295	333	281	342	280	390	335	390	275	267	307	345
8	349	347	371	309	314	357	291	355	303	362	295	314	321	341
9	367	370	349	357	286	299	304	298	331	374	272	317	318	336
10	307	302	320	330	266	310	280	339	295	375	285	293	292	325
Average	360	378	325	371	307	363	304	385	320	407	270	311	314	369

Without consideration of the effect of the crop and comparison with the unmanured soil, the larger amount of manure affected the nitrates proportionately less than did the smaller. The difference between the two treatments favoring 15 tons of manure varied somewhat inversely

with the amount of water applied, the difference being 7.1 p. p. m. with no water and 1.0 p. p. m. with the 40-inch irrigation. In the upper feet the greater accumulation of nitrates under the larger manuring is more clearly evident than in the lower feet, although in almost every foot the difference is in favor of the 15-ton application.

TABLE IV.—*Total nitrates in the fall at various depths in cropped and fallow soil receiving different quantities of manure and irrigation water. Average for three years*

[Results expressed as p. p. m. of sodium nitrate]

CROPPED SOIL

Depth of soil	Total nitrates.																					Average.
	No water.			5 inches of water.			10 inches of water.			20 inches of water.			30 inches of water.			40 inches of water.					
Manure applied (tons)	0	5	15	0	5	15	0	5	15	0	5	15	0	5	15	0	5	15				
Feet.																						
1	18.8	12.7	30.9	19.4	12.1	20.0	17.0	13.3	26.1	12.1	14.5	17.6	11.5	16.4	23.6	9.1	10.3	12.7	16.6			
2	17.6	8.5	23.6	13.9	7.9	12.1	15.2	10.3	14.5	12.1	6.1	10.3	8.5	7.9	13.3	10.9	3.6	12.7	11.6			
3	14.5	7.9	15.2	9.1	7.3	20.6	9.7	12.7	15.8	7.3	6.7	9.1	7.9	6.1	8.5	4.2	3.6	5.5	9.5			
4	21.8	7.3	20.6	13.9	7.9	17.0	12.1	14.5	18.8	9.1	6.7	10.3	10.9	4.2	7.9	4.8	4.8	3.0	10.9			
5	19.4	9.7	22.4	13.3	10.3	9.1	8.5	7.9	13.3	7.9	4.2	11.5	7.9	3.6	5.5	4.8	4.8	12.1	9.8			
6	18.2	15.8	13.3	12.1	9.7	9.7	8.5	6.7	11.5	9.1	3.6	11.5	10.9	4.2	6.1	6.7	11.5	2.4	9.5			
7	15.2	10.3	13.3	12.7	5.5	15.7	9.1	10.3	10.3	12.1	6.1	10.1	13.3	5.5	10.9	7.3	9.1	12.1	10.5			
8	17.6	12.1	12.1	10.3	12.1	16.4	9.7	10.9	10.3	10.9	7.9	9.7	12.7	5.5	12.7	7.9	9.1	2.4	10.6			
9	11.5	8.5	15.2	14.5	10.9	10.3	8.5	12.1	11.5	8.5	6.7	9.1	11.5	6.1	10.9	6.1	6.7	10.3	9.9			
10	6.7	12.1	9.1	9.1	9.7	14.5	13.9	12.7	15.2	10.1	6.7	9.1	6.7	7.9	11.5	4.8	6.1	6.7	9.6			
Average	16.1	10.5	17.6	12.8	9.3	14.5	11.2	11.1	14.7	9.9	6.9	10.8	10.2	6.7	11.1	6.7	7.0	8.0	10.8			

FALLOW SOIL

1	46.7	32.7	89.1	43.6	40.0	107.3	23.6	76.4	44.2	23.6	35.8	30.3	15.8	34.5	43.6	13.3	27.9	26.1	41.9			
2	28.5	27.3	76.3	31.5	27.3	96.4	19.4	64.8	34.5	17.6	36.4	33.9	13.9	37.6	32.7	12.7	18.8	25.5	35.3			
3	36.4	32.1	51.5	30.9	35.8	59.5	16.4	58.2	36.4	15.8	35.2	24.8	17.0	42.4	33.9	20.0	19.4	23.6	32.7			
4	46.1	29.7	47.3	39.4	22.4	61.2	22.4	64.2	33.9	23.0	36.4	35.8	15.2	35.8	25.5	11.5	18.8	20.6	32.7			
5	40.6	32.7	63.6	33.9	33.3	44.8	27.9	41.8	29.1	31.5	41.8	43.6	14.5	23.0	23.6	12.1	24.2	11.0	31.8			
6	39.4	29.1	60.6	37.6	30.9	71.5	32.1	49.7	32.7	30.3	43.0	41.2	14.6	38.2	34.5	15.8	24.2	18.2	36.1			
7	26.7	32.7	81.8	28.5	29.7	55.8	28.5	38.8	29.7	19.4	39.4	38.2	14.5	38.8	37.0	16.4	20.0	17.6	33.0			
8	29.7	23.0	62.4	24.2	23.0	52.7	24.2	31.5	27.3	24.8	24.2	34.0	11.5	27.3	31.0	14.6	28.5	24.2	28.8			
9	23.6	18.2	44.8	13.9	32.7	40.0	23.0	24.2	24.2	24.2	21.2	37.0	12.1	26.7	35.8	12.7	20.6	25.5	25.6			
10	20.6	27.3	64.2	20.0	38.2	61.8	23.6	34.5	27.9	23.0	24.2	32.7	16.4	27.9	31.5	14.0	17.6	21.2	29.3			
Average	33.8	28.5	64.8	30.4	31.3	65.1	24.1	48.4	32.0	23.3	33.8	35.2	14.6	33.2	32.9	14.3	22.0	21.4	32.7			

The tendency for the nitrates to vary inversely with the irrigation water applied is noticed in figure 11 to be more pronounced for no manure and 15-ton applications than for 5-ton applications, but all show a little inclination in this direction. The effect of the irrigation is also seen at almost every foot in depth. As an average, the first two and the middle feet of the unirrigated plots are proportionately higher in nitrates than the other feet when compared with other moisture treatments. The tenth foot of the unirrigated soil is low, in some cases being lower than the plots with water applied. Of the irrigated plots, the top 4 feet of those plots receiving 10 inches and the top foot of those receiving 30 inches of water are high.

NITRATES IN FALLOW SOIL

A consideration of the nitrates found in fallow land, as given in Table IV and figure 12, will show that, except for the plots receiving no water, larger amounts were found in the soils on which an application of 5 tons of manure was made than where no manure was added. With 10 inches of water as an irrigation, the nitrates in the plots receiving 5 tons of manure were double those in the unmanured plots, and more than double with 30 inches of irrigation water. Although the nitrates in the soils receiving no manure and 5 tons differ quite uniformly with regard to depth, each of the first 3 feet of the manured plots contained proportionately more than the unmanured.

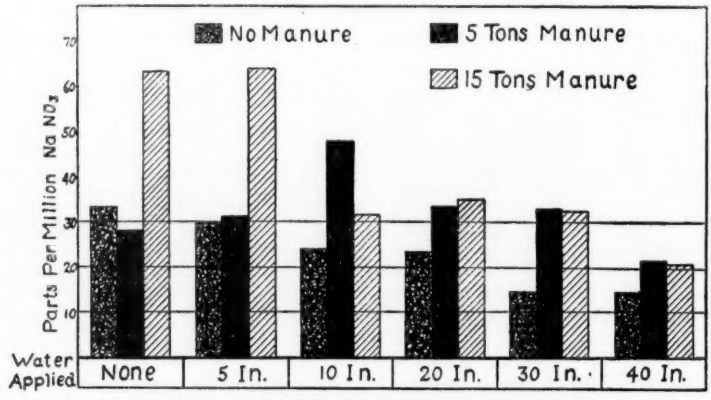


FIG. 12.—Graph showing the nitrates in the fall in fallow soil receiving different quantities of manure and irrigation water. Average of 3 years to a depth of 10 feet.

The soil receiving 15 tons of manure contained, on the average, 5 p. p. m. of nitrates more than did that receiving no manure. This difference was greater for the plots receiving 0 and 5 inches of water than for those receiving more water, and also greater in the upper 2 feet than below this depth.

With no water and with irrigations of 5 inches, the plots on which 15 tons of manure were applied each contained more than twice as high nitrates as did the plots with 5 tons, although with 10, 30, and 40 inches of water the 5-ton applications were better than the 15-ton. The average differences in nitrates between these treatments are a little greater in the first 2 feet than deeper, although the lower 5 feet also show quite a pronounced influence.

As with the cropped plots receiving no manure and 15 tons, the fallow indicates a tendency for the nitrates to decrease with increasing applications of water, while the land receiving 5 tons of manure shows an increase in nitrates until 10 inches of water are applied before the de-

crease began. The average for all manures on fallow land shows that the nitrates began to decrease in amount when the irrigation was 10 inches. The first 5 inches of water applied resulted in more nitrates for the first 3 feet than where no water was applied. The differences in favor of the smaller irrigations appear more in the upper feet than in the lower in most cases.

It may be seen that although the nitrate content of the fallow soils is more than double that of the cropped for no manuring and more than three times for the respective treatments when manure was added, the general relationship between the cropped and fallow plots for nitrates is somewhat similar for the different manuring treatments. This is found both for the water applied and the depth, although the fallow plots are inclined to be more irregular than the cropped ones. The difference between cropped and fallow soils is less pronounced with the larger irrigations than with none or the smaller ones. The proportionate increase in nitrates for increasing amounts of manure is greater for the fallow than for the cropped soils. Fallow and cropped plots differ in nitrate content, on the average, about the same at each foot in depth.

Tables V and VI summarize the effect on soil nitrates of manure and moisture if considered separately.

TABLE V.—*Effect of manure on the nitrates in cropped and fallow soil. Average of all moisture treatments for three years*

[Results expressed as p. p. m. of sodium nitrate]

Depth of soil.	Total nitrates.							
	No manure.		5 tons of manure.		15 tons of manure.		Average.	
	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.
Feet.								
1	14.7	27.8	13.2	41.2	21.8	56.8	16.6	41.9
2	13.0	20.6	7.4	35.4	14.4	49.9	11.6	35.3
3	8.8	22.8	7.4	37.2	12.5	38.3	9.6	32.8
4	12.1	26.3	7.6	34.6	12.9	37.4	10.9	32.8
5	10.3	26.7	6.8	32.8	12.3	35.9	9.8	31.8
6	10.9	28.3	8.5	35.9	9.0	44.1	9.5	36.1
7	11.6	22.3	7.8	33.2	12.0	43.4	10.5	33.0
8	11.5	21.6	9.6	26.2	10.6	38.6	10.6	28.8
9	10.1	18.3	8.5	23.9	11.2	34.6	9.9	25.6
10	8.6	19.6	9.2	28.3	11.0	39.9	9.6	29.3
Average	11.2	23.4	8.6	32.9	12.8	41.9	10.9	32.7

TABLE VI.—*Effect of irrigation water on the nitrates in cropped and uncropped soil. Average of all manure treatments for three years*

[Results expressed as p. p. m. of sodium nitrate]

Depth (feet).	Water applied.													
	None.		5 inches.		10 inches.		20 inches.		30 inches.		40 inches.		Average.	
	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.
1	20.8	56.2	17.2	63.6	18.8	48.1	14.7	29.6	17.2	31.3	10.7	22.4	16.6	41.9
2	16.6	44.0	11.3	51.7	13.3	39.6	9.5	29.3	9.9	28.1	9.1	19.0	11.6	35.3
3	12.5	40.0	12.3	42.0	12.7	37.0	7.7	25.3	7.5	31.1	4.4	21.0	9.5	32.7
4	16.6	41.0	12.9	41.0	15.1	40.5	8.7	31.7	7.7	25.5	4.2	16.9	10.9	32.8
5	17.2	45.6	10.9	37.3	9.9	32.9	7.9	38.9	5.7	20.4	7.2	15.8	9.8	31.8
6	15.8	45.0	10.5	46.7	8.9	38.2	8.1	38.1	7.1	29.1	6.9	19.4	9.5	36.1
7	12.9	47.1	11.3	38.0	9.9	32.3	9.4	32.3	9.9	30.1	9.5	18.0	10.5	33.0
8	13.9	38.4	12.9	33.3	10.3	27.7	9.5	27.7	10.3	23.3	6.5	22.4	10.6	28.8
9	11.7	28.9	11.9	28.9	10.7	23.8	8.1	27.5	9.5	24.9	7.7	19.6	9.9	25.6
10	9.3	37.4	11.1	40.0	13.9	28.7	8.6	26.6	8.7	25.3	5.9	17.6	9.6	29.3
Average.	14.7	42.5	12.2	42.3	12.3	34.7	9.2	30.8	9.4	26.9	7.2	19.2	10.8	32.7

RELATION OF PERCENTAGE OF WATER TO TOTAL SALTS AND NITRATES

To show the average effect of water applied, manure applied, and depth of soil on the moisture, total soluble salt, and nitrate content

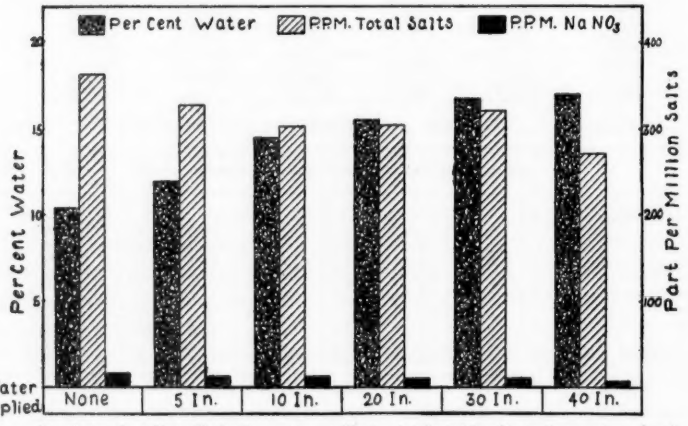


FIG. 13.—Graph showing effect of irrigation water on nitrates, total soluble salts, and percentage of moisture in cropped soil at the close of the cropping season. Average for all manuring treatments during three years to a depth of 10 feet.

of the soil, figures 13, 14, 15, 16, and 17 have been prepared. Some of the conclusions that might be drawn from these averages would not be substantiated when the factors influencing them were considered separately.

While the percentage moisture, total salts, and nitrates all decrease in the cropped soil receiving 5 tons of manure as compared with that receiving none, the total salts show a much greater proportional lessening

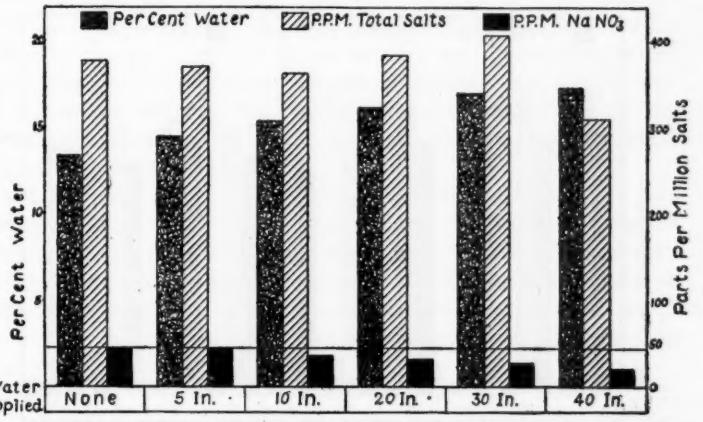


FIG. 14.—Graph showing effect of irrigation water on nitrates, total soluble salts, and percentage of moisture in fallow soil in the fall. Average for all manuring treatments during three years to a depth of 10 feet.

with no irrigation and an application of 5 inches of water than does that of the nitrates at the same treatments, while the moisture percentage decreases because of the manure, about the same amount for each

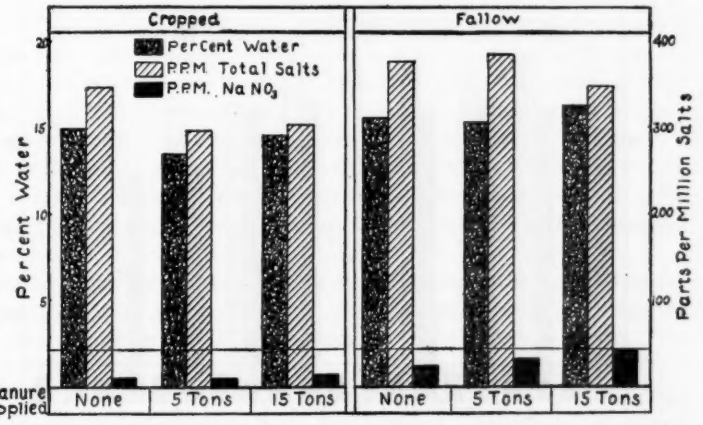


FIG. 15.—Graph showing effect of manure on nitrates, total soluble salts, and percentage of moisture cropped and fallow soil at the close of the cropping season. Average for all moisture treatments during three years to a depth of 10 feet.

irrigation treatment. These differences, while quite evenly distributed in depth for the total salts and nitrates, are greater at the fifth, sixth, and seventh feet for the percentage of moisture.

A comparison of the cropped soil receiving no manure with that to which 15 tons were applied shows the moisture to decrease with the application of this amount of manure for no water and 5 inches of water; the

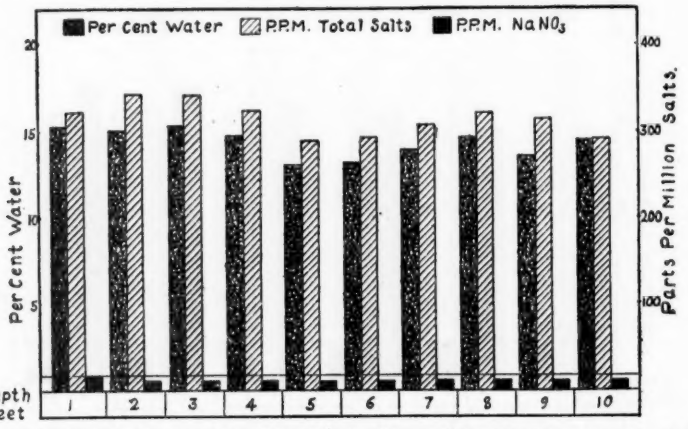


FIG. 16.—Graph showing nitrates, total soluble salts, and moisture at different depths in a cropped soil at the close of the cropping season. Average of all moisture and manuring treatments for three years.

total salts decrease with every irrigation treatment, but show the most marked effect where no water was applied; and the nitrates increase slightly and quite uniformly with all irrigation treatments. Downward,

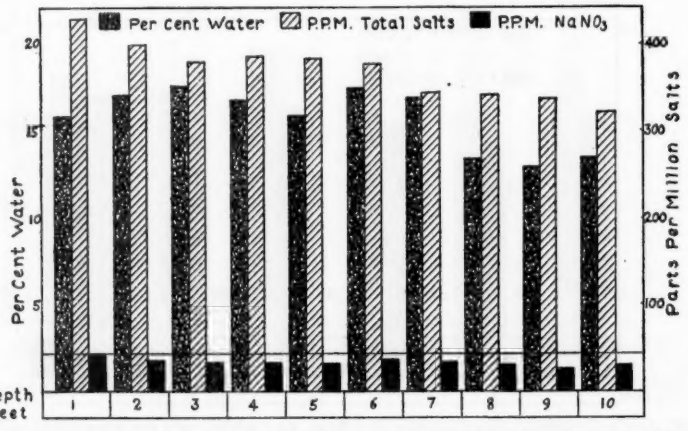


FIG. 17.—Graph showing nitrates, total soluble salts, and moisture at different depths in a fallow soil in the fall. Average of all moisture and manuring treatments for three years.

when averaged for all irrigations, the percentage of water was lower for the manuring only at the fourth, fifth, sixth, and seventh feet, where it was exceptionally low. The total salts of the lower feet of the manured

plots show the effects of the manure strongly, while with nitrates it is noticed most in the top feet.

On the average, moisture, total salts, and nitrates are greater for a manuring of 15 than for 5 tons. This effect is more noticeable for the percentage of moisture with the larger irrigation applications and for the total salts and nitrates with the smaller ones. The nitrates are affected proportionately more by the manure applied than are the total salts or moisture content. For each of the determinations the top feet are influenced more than the lower ones by the larger application, when compared with the 5-ton manuring.

When cropped plots are averaged for manure and depth the data show the moisture content to rise steadily with increasing quantities of irrigation water applied, while, in general, both total salts and nitrates decrease as the amount applied increases. In a comparison of the influence of the irrigations, the nitrates show the greatest effect of the water. The ratio of total salts to nitrates as sodium nitrate rises from 24.5 to 1 without water applied to 37.5 to 1 when 40 inches of irrigation water were used.

For the fallow plots receiving no manure and 5 tons the moisture content of the soil was higher where the manure was not added, while both the total salts and the nitrates were higher with the manure when the irrigation applications were 10 and 5 inches, or more, respectively. The manure affects the nitrates proportionately more than it does either the total salts or percentage water. The nitrates are influenced proportionately more in the top feet than the other two factors discussed here.

If the percentage of moisture in the soil where no water was applied be excepted, the moisture and nitrate content of the fallow plots receiving 15 tons of manure were higher than for those on which no manure was applied, the differences being proportionately greater for the nitrates. The nitrates for these treatments showed the influence of the manure most when the irrigation was 5 inches, and where no water was added. The effect is a little more noticeable in the top feet than lower. The total salts were greater in every case where the soil was not manured than where it received 15 tons to the acre.

The averages for nitrates and percentage of moisture are greater for the 15 than for the 5 tons of manure, although every irrigation treatment for nitrates does not show this tendency. Similar to the nitrates, the total salts increased more for the 15 tons of manure than with 5 tons only on the unirrigated and the 5-inch irrigated plots, but the average for the total salts favors the 5-ton application. The effect of manuring was especially noticeable for the total salts and nitrates in the upper feet, while with the percentage water the differences due to the manure were more evenly distributed for depth.

The averages for the fallow plots show an increase in the moisture content and a decline in the nitrates for increasing applications of water,

as was found for the cropped plots. The total salts do not show the tendency to decrease with increasing water, although the 40-inch applications caused a rather marked decrease over other moisture treatments.

The nitrate decline with increasing water was such that the ratio of the total salts to sodium nitrate increased from about 8.9 to 1 with no water applied to 16.2 to 1 where the application was 40 inches. The increase in the ratio of total salts to nitrates from 10.2 to 1 to 11.7 to 1 between the first and the fourth feet shows the nitrates to decrease more rapidly with increasing depth than do the total salts. It will be noticed that the ratio of total salts to nitric nitrogen is about 10 times what King found it to be for humid soils.

RELATION OF CROPS TO SALTS AND MOISTURE

Figure 18 gives the combined yields of grain and stover per acre for three years of this experiment.

TABLE VII.—*Summary of nitrates, total soluble salts, percentage of soil moisture, and yield of crops with different applications of manure. Average of all moisture treatments for three years*

Quantity of manure.	Moisture.		Sodium nitrate.		Total soluble salts.		Crop yields.
	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	
	Per cent.	*Per cent.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*Tons.*
None	14.9	15.5	11.2	23.4	345	377	4.106
5 tons	13.4	15.2	8.6	32.9	296	384	6.273
15 tons	14.5	16.2	12.8	41.9	302	347	7.053
Average	14.3	15.6	10.9	32.7	314	369	5.811

TABLE VIII.—*Summary of nitrates, total soluble salts, percentage of soil moisture, and yield of crops with different irrigation treatments. Average of all manurings for three years*

Water applied.	Moisture.		Sodium nitrate.		Total soluble salts.		Crop yields.
	Cropped.	Fallow.	Cropped.	Fallow.	Cropped.	Fallow.	
	Per cent.	*Per cent.*	*P. p. m.*	*P. p. m.*	*P. m. p.*	*P. p. m.*	*Tons.*
None	10.3	13.4	14.7	42.5	360	378	5.155
5 inches	11.9	14.5	12.2	42.3	325	371	5.993
10 inches	14.4	15.4	12.3	34.7	307	363	6.026
20 inches	15.4	16.2	9.2	30.8	304	385	6.246
30 inches	16.7	17.0	9.4	26.9	320	407	5.891
40 inches	16.9	17.3	7.2	19.2	270	311	5.582
Average	14.3	15.6	10.8	32.7	314	369	5.811

In Tables VII and VIII are found the summarized results of the effect of manure and water, respectively, on the moisture, total salts, and nitrates found in the soils from which the crops were taken, compared with adjacent land on which no crops had been grown. The increase in crop is much greater in proportion for 5 tons than for 15. Except for the 5-inch application of water with 15 tons of manure, the largest yields were secured with 20 inches of water. The effect of cropping is felt

proportionately more for the nitrates than for the percentage moisture or total salts; the greatest effect of the crop on the moisture and total salts being felt on the plots which received 5 tons of manure, and for nitrates with 15 tons if we consider the difference in these factors between cropped and fallow plots to have all gone to the crop. The effect of the crop on the moisture content is more marked for no and 5 inches of water than for the larger amounts and is more for these quantities of water with 15 tons of manure than with the other manuring treatments.

The difference between cropped and fallow plots for nitrates is greater, as an average, with no and 5 inches of water, the loss due to the crop being greatest for 15 tons of manure.

In general, then, it may be said that, although cropping reduces the percentage of moisture, the total salts, and nitrates of the soil, the

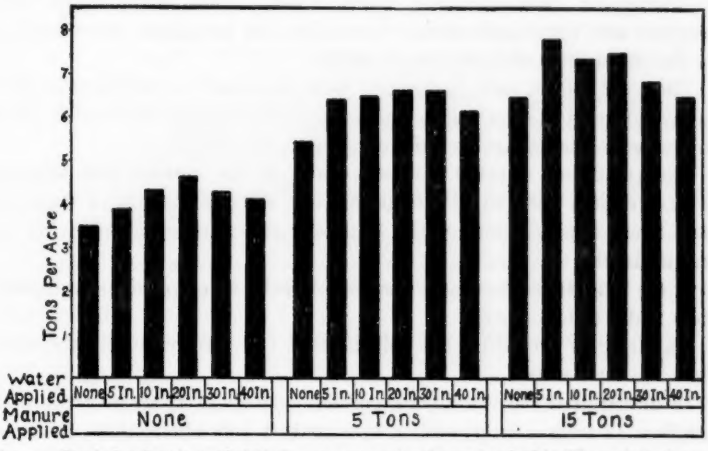


FIG. 18.—Graph showing the total yield of corn stover and grain produced with different irrigation and manuring treatments. Average for three years.

reduction does not seem to bear as close relationship to the crop yield as to the water and manure applied. More nitrates are formed with rather low percentages of water, and the plants seem to use more nitrate nitrogen where water is not plentiful than where more is given.

SUMMARY

Three distinct sets of experiments are reported in this paper.

With a sod soil held in the laboratory for 2½ years, the total salts and nitrates accumulated most rapidly with a moisture content between 23 and 28 per cent.

Cropped and uncropped soil kept in large tanks under controlled moisture conditions showed a decrease in nitrates and total soluble salts as the percentage of moisture increased, the nitrates being particularly low in water-logged soil.

Under field conditions more nitrates were found in both cropped and fallow soils during the summer than just after the corn crop was harvested.

The nitrates of the fallow field soils averaged higher with a manuring of either 5 or 15 tons to the acre than with no manure, but on the cropped soil, although the 15-ton application of manure resulted in more nitrates than no manure, the 5-ton did not. The fallow soil showed the effect of the manure on the nitrates more in the top 2 or 3 feet than at lower depths.

The highest soluble-salt content of fallow soil was on plots manured at the rate of 5 tons to the acre; the lowest was on plots receiving 15 tons. The corresponding high and low points in cropped soil were on plots receiving no manure and 5 tons to the acre, respectively.

Unirrigated land contained more nitrates than irrigated on both cropped and uncropped plots. Increasing the irrigation water applied to the soil decreased its nitrate content.

The total soluble salts in cropped plots decreased as the water applied increased and in fallow soil an application of 40 inches of water resulted in less salts than where no irrigation water was added.

The treatment affected the salts more in the surface foot than at greater depths with small irrigations, but when 20 inches of water or more were applied some of the salts seemed to have moved below 10 feet in depth.

Large irrigations decreased the soluble salts in cropped more rapidly than it did in fallow soils.

Manuring or irrigating the soil affected the nitrates relatively more than the total salts.

In unmanured soil the nitrate content was about twice as great with a fallow as with a crop, and in manured, it was about three times as great.

The ratio of total soluble salts to the quantity of sodium nitrate found in a cropped soil rose from 24.5 to 1 without irrigation to 37.5 to 1 when 40 inches of water were used. The ratio in fallow soil increased from 8.9 to 1 with no irrigation water to 16.2 to 1 with 40 inches.

The field results do not indicate a close relationship between the crop yield and the total soluble-salt or the nitrate content of the soil if the differences between cropped and fallow soils indicate the amounts of these substances which the crop used.

After a consideration of both pot and field experiments, it is evident that the soluble salts and especially the nitrates are found in lower concentrations in soils receiving large quantities of irrigation water than in those receiving less water. This is probably due in part to the leaching action of the heavy irrigations as well as to the lower nitrification in the presence of excessive soil moisture.

LITERATURE CITED

(1) BUCKMAN, H. O.
1910. Moisture and nitrate relations in dry-land agriculture. *In* Proc. Amer. Soc. Agron., v. 2, p. 121–138, fig. 19–22.

(2) CARDIFF, I. D.
1915. Soil moisture investigations. *In* Wash. Agr. Exp. Sta. Bul. 127 (25th Ann. Rpt. [1914]/15), p. 15–20.

(3) HALL, A. D.
1905. The Book of Rothamsted Experiments. 294 p., 49 fig., pl. London.

(4) JENSEN, C. A.
1910. Seasonal nitrification as influenced by crops and tillage. U. S. Dept. Agr. Bur. Plant Indus. Bul. 173, 31 p., 7 fig.

(5) ———
1916. Nitrification and total nitrogen as affected by crops, fertilizers, and copper sulfate. *In* Jour. Amer. Soc. Agron., v. 8, no. 1, p. 10–22.

(6) JOHANSSON, S.
1910. The movement of nitrates in clay soils. (Abstract.) *In* Exp. Sta. Rec., v. 25, no. 2, p. 116. 1911. *Original article in* Verhandl. Internat. Agrogeol. Konf. [Stockholm], bd. 2, p. 149–159. 1910. *Not seen.*

(7) KING, F. H.
1905. Investigation in soil management. Part II. Relation of crop yield to the amounts of water-soluble plant-food materials recovered from soils. *In* U. S. Dept. Agr. Bur. Soils Bul. 26, p. 79–124, fig. 4–9, pl. 1.

(8) ———
1907. A Text Book of the Physics of Agriculture. ed. 4, 604 p., 276 fig. Madison, Wis.

(9) LAWES, J. B., GILBERT, J. H., and WARINGTON, R.
1890. The nitrogen as nitric acid in the soils and subsoils of some of the fields at Rothamsted. *In* Rothamsted Mem., v. 5, no. 22, 39 p.

(10) LYON, T. L., and BIZZELL, J. A.
1913. Some relations of certain higher plants to the formation of nitrates in soils. N. Y. Cornell Agr. Exp. Sta. Mem. 1, p. 1–111, 27 diagr.

(11) MCINTIRE, W. H.
1912. Some results of 30 years' treatment with barnyard manure. *In* Penn. Agr. Exp. Sta. Ann. Rpt. 1911/12, p. 57–63.

(12) RUSSELL, E. J.
1914. The nature and amount of the fluctuation in nitrate content of arable soils. *In* Jour. Agr. Sci., v. 6, no. 1, p. 18–57, 2 fig.

(13) STEWART, Robert, and GREAVES, J. E.
1909. A study of the production and movement of nitric nitrogen in an irrigated soil. Utah Agr. Exp. Sta. Bul. 106, p. 69–96.

(14) ——— ———
1911. The movement of nitric nitrogen in soil and its relation to "nitrogen fixation." Utah Agr. Exp. Sta. Bul. 114, p. 181–194.

(15) TULAIKOV, N.
1915. The nitric nitrogen of the black soils of the arid regions of Russia. (Abstract.) *In* Exp. Sta. Rec., v. 34, no. 7, p. 618. 1916. *Original article in* Selsk. Khoz. i Lîesov., t. 247, god 75, p. 35–65. 1915. *Not seen.*

(16) WATT, R. D.
1909. Nitrification in Transvaal soils. *In* Transvaal Agr. Jour., v. 7, no. 26, p. 202–204.

(17) WEIS, Fr.
1909. Om Salpetersyrens Forekomst og Dannelse i Muld og Mor. *In* Forstl. Forsøgsv., Bd. 2, Haefte 2, p. 257–296.